LIFE HISTORY CHARACTERISTICS, MANAGEMENT STRATEGIES, AND ENVIRONMENTAL AND ECONOMIC FACTORS THAT CONTRIBUTE TO THE VULNERABILITY OF ROCKFISH STOCKS OF ALASKA

By

Jacqueline Patt

RECOMMENDED: ______________________________
Dr. Jonathan Heifetz

____
Dr. Milton Love

____
Dr. Anthony Gharrett
Advisory Committee Co-Chair

____
Dr. Keith Criddle
Advisory Committee Co-Chair

____
Dr. Shannon Atkinson,
Chair, Graduate Program, Fisheries Division

APPROVED: ______________________________
Dr. Michael Castellini
Dean, School of Fisheries and Ocean Sciences

____
Dr. John Eichelberger
Dean of the Graduate School

12/7/14
____
Date

LIFE HISTORY CHARACTERISTICS, MANAGEMENT STRATEGIES, AND ENVIRONMENTAL AND ECONOMIC FACTORS THAT CONTRIBUTE TO THE VULNERABILITY OF ROCKFISH STOCKS OFF ALASKA

A

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Jacqueline Patt, B.S.

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Abstract

This study explored the extent to which variations in biological characteristics, environmental and economic factors, and management strategies have affected the tendency for rockfish to become overfished. The analysis used data on 5 species of rockfish that account for more than 95% of commercial catch of rockfish in the Gulf of Alaska (GOA) and Bering Sea and Aleutian Island (BSAI) management regions. These species are: Shortraker Rockfish (*Sebastes borealis*), Pacific Ocean Perch (*Sebastes alutus*), Northern Rockfish (*Sebastes polyspinis*), Dusky Rockfish (*Sebastes variabilis*), and Shortspine Thornyhead (*Sebastolobus alascanus*). Fishery management models often treat B_{MSY}, the biomass level that maximizes sustainable yield, as a critical reference point; whenever the biomass of a federally managed fish or shellfish stock is estimated at less than $0.5 \times B_{MSY}$, the stock is declared "overfished" and managers are required to develop a recovery plan that will restore stock abundance above B_{MSY} within about one generation length. Because estimates of B_{MSY} are unavailable for some GOA and BSAI rockfish stocks included in this analysis and because we were interested in developing a model that could be applied to data-poor stocks, we explored two proxies for B_{MSY}. The mean of past estimates of exploitable biomass (*avgExpB*) was used as a proxy for B_{MSY} for the better-studied stocks. The mean of past catch (*avgC*) was used as a proxy for B_{MSY} for data-poor stocks. These values were used to scale time series estimates of exploitable biomass ($ExpB_t$) or catch (C_t). A systems estimation approach, seemingly unrelated regression (SUR), was used to estimate parameters of linear and nonlinear models that included available numerical and categorical variables (biological, management, environmental, and economic factors) thought to contribute to increases or decreases in $ExpB_t$ / *avgExpB* or C_t / *avgC*. Goodness-of-fit statistics and tests of individual coefficients and groupings of coefficients were used to guide model refinement.

The modeling approach worked well for better-studied stocks but not for data-poor stocks. The preferred 5-stock model (Pacific Ocean Perch in the GOA and BSAI, Northern Rockfish in the GOA and BSAI, and Dusky Rockfish in the GOA) had an excellent fit to the overall system ($R^2 = 0.922$, $P << 10^{-6}$) and statistically significant coefficient estimates of the variables included. The model indicated that the past values of $ExpB_t$ / $avgExpB$ can be accounted for through time and across stocks by nonlinear variation in: *spawning biomass*, *intrinsic growth rates* (k), *maximum age*, *exploitation rates*, *habitat preferences*, *Pacific Decadal Oscillation*, and *ex-vessel price*. Because some of these factors are subject to management control and others are predictable, it should be possible to take account of anticipated changes in these factors when setting harvest targets and harvest limits, selecting spatial management strategies, or considering changes to harvest control rules or fisheries governance systems.

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Life history characteristics, management strategies, and environmental and economic factors that contribute to the vulnerability of rockfish stocks off of Alaska

1. Introduction[1]

1.1 Historical and Current Status of Alaskan Rockfish Fisheries

The state and federal governments share responsibility for rockfish management. The state takes responsibility for catches within 0 - 3 nautical miles of the coast and for some species that predominantly occur within that zone, and the federal government takes responsibility for catches from 3 - 200 nautical miles off the coast. Pacific Ocean Perch (*Sebastes alutus*) and Northern Rockfish (*Sebastes polyspinis*) comprise approximately 75% of the total rockfish biomass in the Gulf of Alaska (GOA) and more than 90% of the rockfish biomass in the less species-rich Bering Sea/Aleutian Islands (BSAI) region (NPFMC, 2013a. and NPFMC, 2013b.). In the federally managed portions of the GOA, Pacific Ocean Perch, Northern Rockfish, Shortraker Rockfish (*Sebastes borealis*), and Dusky Rockfish (*Sebastes variabilis*) are managed as individual species and all other GOA rockfish are managed as species complexes: the Rougheye Rockfish (*Sebastes aleutianus*) / Blackspotted Rockfish (*Sebastes melanostictus*) complex, the demersal shelf rockfish complex, the thornyhead rockfish complex, and the "other rockfish" complex (NPFMC, 2013a; 2013b). In federally managed portions of the BSAI, Pacific Ocean Perch, Northern Rockfish, and Shortraker Rockfish are managed as individual species while Rougheye Rockfish and Blackspotted Rockfish are managed as a complex and the

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remaining rockfish species commercially harvested in the BSAI [mostly Shortspine Thornyheads (*Sebastalobus alascanus*) and Dusky Rockfish] are managed as the "other rockfish" complex (Lowe and Spencer, 2009; NPFMC, 2013a**).**

Foreign fleets participated in Alaska's groundfish fisheries from the 1960s through the mid-1980s. Participation of domestic fleets increased during the 1980s, and by the late 1980s/early 1990s these fisheries had become primarily domestic. The domestic groundfish fishery off Alaska is the largest fishery by weight in the U.S.; the total catch varied between 1.521 and 2.191 million metric tons (t) during the last 10 years (Fissel et al., 2014). In 2012, the ex-vessel value of GOA rockfish catch was $15.7 million; the ex-vessel value of BSAI rockfish catch was $17.1 (Fissel et al., 2014). Between 2008 and 2012, trawling accounted for 95.8% of rockfish catch in the GOA and 99.2% in the BSAI (Fissel et al., 2014).

Rockfishes are long-lived and have high fecundities, which means that each sexually mature female contributes large numbers of offspring, most of which die before reaching maturity (Drake et al., 2010). Chance variability in survival of offspring could lead to circumstances in which a few females contribute large numbers of offspring to the subsequent generation whereas others, perhaps even a majority, do not contribute at all. Recruitment can also vary temporally. The level of recruitment for a given stock may be influenced by: climate, predator abundance, oceanic currents, and other environmental conditions (Drake et al., 2010). As a consequence of interannual variability in climate, there are a few strong year classes and many weak ones, which make rockfish particularly vulnerable to depletion since it would take much longer for their populations to recover than it would for species with consistent annual recruitment levels (Yoklavich, 1998).

Pacific Ocean Perch, while currently the most abundant rockfish species in the GOA, has experienced overfishing in the past and may have genetically distinct stocks that could become locally depleted (Gharrett et al., 2007). Some of the rockfish within management assemblages also may be at risk of depletion. For instance, in 2010, the GOA Shortraker Rockfish and "other slope rockfish" assessment recommended that two of the included species, Silvergray Rockfish (*Sebastes brevispinis*) and Harlequin Rockfish (*Sebastes variegatus*), be further assessed to determine whether they are a conservation concern (Clausen, 2010). However, the 2011 and 2013 GOA trawl surveys indicated high estimated biomass for Silvergray Rockfish in 2011 and 2013 and for Harlequin Rockfish in 2013. Although they are no longer conservation concerns, the biomass trends for these and other rockfish species suggest that environmental conditions may significantly affect rockfish abundance (Tribuzio and Echave, 2013).

1.2 Federal Management

The majority of the commercial groundfish catch off Alaska is managed by the National Marine Fisheries Service (NMFS) under the Fishery Management Plans (FMP) for the GOA and the BSAI groundfish fisheries (NPFMC, 2013a; 2013b). Catch quotas for rockfish managed by the North Pacific Fishery Management Council (NPFMC) are divided among five regions: the eastern, central, and western GOA; the Aleutian Islands (AI); and the eastern Bering Sea (EBS) (Lunsford et al., 2004; Hawkins et al., 2005).

1.3 State Management

Rockfish fisheries in nearshore waters are managed by the Alaska Department of Fish and Game (ADF&G). Nearshore stocks support small commercial and recreational fisheries. Data show that the number of anglers fishing for rockfish and the total catch of rockfish has increased over the last few decades (ADF&G, 2012). Rockfish are mostly caught in the sport fishery for

Pacific Halibut (*Hippoglossus stenolepis*) but some sport fishing charters offer Pacific Halibut/rockfish combination trips and even rockfish-only trips. The rockfish species most frequently caught by sport fishermen in Alaska are: Yelloweye Rockfish (*Sebastes ruberrimus*), Quillback Rockfish (*Sebastes maliger*), Dusky Rockfish, Dark Rockfish (*Sebastes ciliatus*), Copper Rockfish (*Sebastes caurinus*), and Black Rockfish (*Sebastes melanops*) (ADF&G, 2012). As the popularity of sport fishing for rockfish grows, there could be risk of localized depletion of these species.

1.4 Federal Management - Harvest Controls

The NPFMC uses information from biannual stock assessments in conjunction with models of rockfish population dynamics and a system of harvest control rules to set an annual allowable biological catch (ABC) for each species or species assemblage (NMFS, 1999). The harvest control rules are graduated into tiers (numbered 1 - 6) that reflect differences in the quality of information available for estimation of population parameters and the confidence in those estimates (NMFS, 1999). Rockfish species in Alaskan waters are managed under tier 3, tier 4, or tier 5 (Clausen and Echave, 2011). For species in tier 3, the data for spawner-recruit relationships of stocks is insufficient to estimate MSY or B_{MSY}; however, there is sufficient data to determine $F_{40\%}$, a proxy for MSY and $B_{40\%}$, a proxy for B_{MSY} (Goodman et al., 2002). $F_{40\%}$ is the fishing mortality rate that reduces spawning biomass per recruit to 40% of the estimated unfished level. $B_{40\%}$ refers to the long-term average biomass that would be expected under average recruitment and when $F = F_{40\%}$. Because less data are available for species placed in tiers 4 - 6, these species are managed and harvested more conservatively than those placed in tiers 1 – 3 (Goodman et al., 2002). The tier 5 criteria state that the F_{ABC}—the fishing mortality rate used to calculate the ABC—should not exceed 75% of M (natural mortality), whereas for tier 3 and tier 4, F_{ABC} is not greater than $F_{40\%}$. . Overfishing for a tier 5 species is defined to occur when fishing mortality on that species equals or exceeds its estimated natural mortality ($F_{OFL} = M$). For tier 3 and tier 4 species overfishing occurs whenever $F_{OFL} > F_{30\%}$ (NMFS, 1999).

1.5 Regulatory Complexes

Many rockfish species in the GOA and the BSAI are grouped into complexes because there is insufficient information on their identification, abundance and distribution to manage them as individual stocks and in recognition of the tendency for some species to aggregate as multispecies assemblages (Musick et al., 2000; Love et al., 2002). However, as new information has become available or when catches of particular species within the complex appear disproportionately greater than their occurrence within the complex, species are moved out of or between rockfish management complexes (Lunsford et al., 2004; Clausen et al., 2011). For example in 2010, the GOA Groundfish Plan Team recommended that Dusky Rockfish be removed from the pelagic shelf rockfish complex and managed separately (Clausen and Echave, 2011; Clausen et al., 2011). Similarly, Dark Rockfish were removed from the federal management Fishery Management Plan to be managed by the State of Alaska in 2008 because the preponderance of catch of Dark Rockfish was from State waters (NPFMC, 2003). Nevertheless, many rockfish species continue to be managed as complexes either because of lack of data, overlapping habitat, or out of desire for a simplified management regime. Because the complexes include species with differing life history characteristics, management as a complex may increase the risk of over-exploitation of constituent species that are slower growing, more easily caught, or more highly desired by commercial or sport fishers. In addition, managing multiple species within a complex may fail to account for the decline of one species within the complex if there are offsetting increases in the abundances of other species in the complex. Even if the OFL of the declining species is exceeded, this would not trigger any management action unless the overall OFL for the complex has been exceeded (Clausen and Echave, 2011). In the GOA, for example, notable declines in Harlequin Rockfish have been observed in the past few years; but, because it is managed as part of the "other rockfish" complex, little action has been taken to manage Harlequin Rockfish more conservatively (Clausen and Echave, 2011). Thus, the removal of additional rockfish species from management complexes may be necessary to ensure biological sustainability.

1.6 Bycatch and Discards

By choosing when and where they fish, what type of fishing gear to use, and how to deploy and retrieve that gear, fishers seek to influence the tonnage and mix of species they catch. However, while these choices affect the probability of catching particular species, they do not provide precise control of what is caught. Moreover, depending on ex-vessel value and on costs and catch rates, fishers may intentionally seek to catch a varied mix of species. From a fishers' perspective, bycatch is any fish that they did not intend to catch and cannot market. Regulators often adopt a simple pragmatic definition for bycatch: it is the catch of any species other than the species that comprises the largest percentage of the catch (Criddle, personal communication, 2012). All are agreed on the need to ensure that the sum of intended catch and bycatch does not exceed the ABC. There is less agreement on how to partition the ABC between catch and bycatch or on how and whether to subdivide catch and bycatch limits among gear groups and regions.

Because rockfish are often taken incidental to fisheries for Pacific Halibut, Sablefish (*Anoplopoma fimbria*), Pacific Cod (*Gadus macrocephalus*), and Atka Mackerel (*Pleurogrammus monopterygius*), substantial quantities of rockfish catch is recorded as "bycatch". However, because many species of rockfish command high ex-vessel prices, it is possible for the landed value of rockfish bycatch to exceed the landed value of the ostensible target species. In these situations it is common for fishermen to "top-off" their hauls with the bycatch species. Concern about how valuable catch and bycatch are allocated among gear groups and regions has led to the adoption of management measures that hold particular gear groups to catch limits and maximum retainable bycatch as a percentage of the directed catch. However, a perverse consequence is that those limits can lead to circumstances where fishers are legally required to discard dead and dying fish that would have considerable dockside value.

1.7 Research Objectives

Alaska rockfishes exhibit a diversity of life history traits including variation in habitat preferences, diet preferences, fecundity, maximum lifespan, age at maturity, size at maturity, and natural mortality. In addition, species may differ in their sensitivity to variations in the environment. Differences in market value may also affect the intensity of fishing effort on particular species. These differences may affect vulnerability to overfishing. This study uses multiple regression analysis to determine which of these characteristics predispose some rockfish species to a greater risk of being overfished.

2. Materials, Methods, and Model Specification

2.1 Data

Choice of the rockfish species included in this study was based on the amount of biological data available and on the importance of these species to the Alaska commercial groundfish fishery. In addition, species were selected to emphasize contrasting exposure to target and non-target fisheries, varied management regimes, and differing life history characteristics. The 5 species selected for study were: Shortraker Rockfish, Pacific Ocean Perch, Dusky Rockfish, Northern Rockfish, and Shortspine Thornyhead. Data sources used to characterize GOA and BSAI stocks of and fisheries for these species are listed in Tables 1 – 9. The geographic range of the study included the GOA and the BSAI region. Rockfish life histories, population trends, environmental conditions, economic value, and historical and current management regimes for BSAI and GOA groundfish fisheries were examined to determine which factors most affect rockfish stock status.

Information about current and historical management strategies dating back to the late 1980s was obtained from the GOA and BSAI groundfish stock assessment and fishery evaluation (SAFE) reports (Jon Heifetz, NOAA fisheries, personal communication 2012; NPFMC, 2011; 2013a; 2013b). Historical and current management tier levels, total biomass estimates, total catch, ABC, spawning biomass estimates, recruit estimates, exploitable biomass estimates, method of fishing (i.e. gear type), and values for k and M were also obtained from NPFMC (2013a; 2013b) (Tables 1 - 9). Life history data, such as habitat preference, depth range, maximum lifespan, age at 50% maturity, length at 50% maturity were obtained from 2012 GOA and BSAI SAFE documents.

Monthly values of the Pacific Decadal Oscillation (PDO) index were obtained from the University of Washington Joint Institute for the Study of the Atmosphere and Ocean (http://jisao.washington.edu/pdo/PDO.latest). Annual ex-vessel rockfish prices were obtained from queries on the Alaska Department of Fish and Game (ADF&G) Fish Ticket database (Jennifer Shriver, Alaska Commercial Fisheries Entry Commission, personal communication, 2013). Time-series observations of average ex-vessel prices were differentiated according to fishing method (i.e. fixed gear versus trawling) and adjusted to offset inflation. Because rockfish caught by longline have a higher economic value than those caught by trawl, ex-vessel prices were weighted to reflect the percentage of rockfish caught by longline and the percentage caught by trawl. Prices were adjusted to a 2010 base by using the consumer price index. GOA price data were used for BSAI landings because confidentiality rules precluded release of BSAI-specific records for several years in the time series.

Each numerical data series was rescaled to reduce heteroskedasticity. For example, the mean of all of the observations of spawning biomass for a given stock was subtracted from each annual observation of spawning biomass for that stock and the resulting value was divided by the sample standard deviation for that stock. This transformed each time series of numerical data into scale-free values characterized by a mean equal to 0 and a standard deviation equal to 1.

2.2 Data Analysis

Multiple regression models were used to explore the correlation between life history traits and management measures on rockfish population status. Species were selected to emphasize contrasting exposure to target and non-target fisheries, varied management regimes, and differing life history characteristics. The questions that motivate this analysis include: 1. Are there life history characteristics or environmental and economic factors that make Alaska rockfish species susceptible to becoming overfished and if so, what are they? 2. Which of those species examined are in greatest jeopardy of becoming overfished?

The mean of past estimates of exploitable biomass, *avgExpB*, was used as a proxy for B_{MSY} for a joint model of the 5 tier 3 rockfish stocks: GOA and BSAI Pacific Ocean Perch, GOA and BSAI Northern Rockfish, and GOA Dusky Rockfish (Figure 1). Because estimates of exploitable biomass are not available for tier 4 or tier 5 stocks, those stocks could not be included in the tier 3 analysis. Instead, GOA and BSAI stocks of Shortraker Rockfish and GOA and BSAI stocks of Shortspine Thornyhead were used to fit and test models that used the mean of past catch, *avgC*, as a proxy for B_{MSY} and time series estimates of catch as proxies for time series estimates of exploitable biomass. A systems estimation approach, seemingly unrelated regression (SUR), was used to estimate parameters of linear and nonlinear models that included readily available numerical and categorical variables (biological, management, environmental, and economic factors) thought to contribute to increases or decreases in $ExpB_t$ / *avgExpB* or C_t / *avgC* (Zellner, 1962). Goodness-of-fit statistics and tests of individual coefficients and groupings of coefficients were used to guide model refinement.

The data included in the tier 3 model were time series of historical and current fishing methods for each species, biomass estimates, catch trends, and the geographic location(s) of fishing. Specifically the tier 3 models included linear and nonlinear functions of: exploitable biomass, spawning biomass, recruitment, natural mortality, growth rates, maximum age, age at 50% maturity, length at 50% maturity, catch, exploitation rate, ABC, habitat preferences, the PDO index, and ex-vessel price. Many of these variables are not available for tier 4 or tier 5 stocks. Consequently, the tier 4/5 models did not include estimates of exploitable biomass, spawning biomass, recruitment, or ABC. Habitat preference was characterized by substrate type (mud/sand substrate, rocky substrate, or rocky/biogenic substrate, or biogenic substrate).

Based on a review of the literature and generally observed behavior of the biological, management, environmental, and economic variables include in the model, it was possible to anticipate the sign and order of magnitude of coefficients to be estimated in the model. It was hypothesized that rockfish species that are longer-lived and slower to mature will be at greater risk of becoming overfished than shorter-lived, early-maturing species (Beamish et al., 2006; Norse et al., 2011; Hixon et al., 2014. Moreover, larger fish, which are more fecund, are more likely to be removed by recurrent fisheries. Rockfish that have a late age at maturity are more likely to be caught by a fishing vessel before having the chance to reproduce and thus replenish their population. It was hypothesized that rockfish species that have low fecundity, form schools, and prefer habitats and depths that are readily fished will also be prone to overexploitation (Myers and Barrowman, 1996; Johnson, 2007). Fecundity was not included in the regression models because little or no fecundity data were available for the species chosen for the study.

Because variations in environmental conditions may affect rockfish recruitment, the PDO, an index of widespread low-frequency environmental variation, was included in the data to be used for model selection. The PDO is an index of sea surface temperature anomalies in the North Pacific Ocean (Mantua et al., 1997). It varies on a multi-annual scale alternating between warm and cool phases. The PDO has been linked to variations in upwelling intensity and current velocity in the Gulf of Alaska and Bering Sea. Estimates of the monthly PDO indices (http://jisao.washington.edu/pdo/PDO.latest) were obtained from the University of Washington Joint Institute for the Study of the Atmosphere and Ocean and used to generate an annual time series of the mean of the May-Oct PDO indices. The PDO reflects processes that may affect ecosystem productivity on a multi-decadal scale. Physical environmental factors correlated with the PDO include sea surface temperature and sea level pressure (Mantua and Hare, 2002). Biological factors, such as trends in productivity, may correlate with shifts in PDO regimes (Hare and Mantua, 2000). Depending on life history characteristics, marine organisms may respond differently to climate change; some species respond quickly and others respond slowly or experience indirect effects of climate change (Miller and Sydeman, 2004). Relatively long-lived species such as rockfish would, therefore, be more likely to experience indirect or lagged effects from low frequency changes in environmental conditions.

Time series observations of rockfish biomass estimates, catch trends, and ABC for each species were used in the analysis. It was hypothesized that rockfish stocks with trends of high catches and low biomass estimates are at higher risk of becoming overexploited.

The biomass level that is capable of supporting catches that maximize sustainable yield, B_{MSY}, is typically used as a gauge of stock status. Stock levels above B_{MSY} are considered to be at low risk of overexploitation; stock levels below B_{MSY} but above 50% B_{MSY} are considered to be at moderate risk of overexploitation; stock levels below 50% B_{MSY} are often considered overexploited (NMFS, 1999). Dividing current biomass by B_{MSY} provides a scale-free measure of exploitation intensity that facilitates comparisons across species. When values of this ratio are below 0.5, fishery managers are required to develop and implement a stock recovery plan that has a reasonable probability of resulting in biomass rising to at least B_{MSY} within about one generation. If the stock is not undergoing a mandatory rebuilding plan and the stock is between 0.5 and 1, it is anticipated that managers will take actions to reduce fishing pressure so that the stock does not become overfished; stocks with ratios above 1 are thought to be at low risk of becoming overfished.

Unfortunately, estimates of B_{MSY} have not been available for most of the tier 3 species until recently. Instead, average exploitable biomass (*avgExpB*) was used as a proxy variable for B_{MSY} for the tier 3 models. For the tier 3 models (equation 1) the dependent variable was the ratio of annual exploitable biomass estimates ($ExpB_t$) to the average exploitable biomass across the time series:

(1) $ExpB_t \,/\, avgExpB = f$(biological, management, environmental, and economic factors)

Linear, polynomial, and exponential functional forms of equation (1) were fit to data representing the tier 3 stocks modeled in this study.

For tier 4 and tier 5 species, there are no estimates of B_{MSY} or exploitable biomass, so there are no proxies for B_{MSY} and no basis for concluding that the stock is or is not overfished (Goodman et al., 2002). As an alternative, we explored a set of models that used the ratio of catch (C_t) to average catch ($avgC$) as a proxy biological reference point. The models represented by equation (2) examine which parameters most influence catch to rise above or drop below the average. The model was expected to reveal which factors are most important in affecting the status of species with similar life histories and/or fishery conditions.

(2) $C_t \,/\, avgC = g$(biological, management, environmental, and economic factors)

Linear, polynomial, and exponential functional forms of equation (2) were the basis for estimates for tier 4 and tier 5 stocks modeled in this study.

Time series estimates of exploitable biomass and catches from 1979 through 2011 were used in this study. Information on relative abundance over time helped to correlate rockfish stock resilience with factors such as changes in fishing pressure, altered environmental conditions, or year-class strength. Equations (1) and (2) included time series observations on rockfish market value because high market value may generate increased fishing pressure and make a species more vulnerable to depletion. Data on harvest rates in terms of biomass and abundance and information on the primary gear type (longline vs. trawl) used in each fishery considered were also used.

The time series data for the tier 3 and tier 4/5 models were pre-tested for multicollinearity with a Pearson's linear correlation test statistic on the matrix of data. If two or more variables are highly collinear (i.e., the variables are linearly interdependent or coincidently exhibit similar patterns of variation over the time span of available observations), their inclusion in a regression model could prevent the model from being solved and, even if a solution was reached, the presence of collinearity would reduce the statistical significance of coefficient estimates. High levels of collinearity were observed among variables representing age at 50% maturity, natural mortality, growth rate, and length at 50% maturity. In addition to omitting some of these collinear variables, we also removed variables that had low variability. For example, the estimate of natural mortality, which did not vary through time for individual species and only varied slightly among species, was eliminated. Although there were only 10 to 30 observations per time series, by estimating the model as a seemingly unrelated regression (SUR) simultaneous equation system across all six stocks, there were 132 observations to contribute to parameter estimation (Zellner, 1962).

Following the preliminary analyses, predictions were made of the coefficient sign for each variable based on the hypothesized effect of each parameter on the dependent variable (e.g., for tier 3, $ExpB_t$ / $avgExpB$). Variables that were hypothesized to lead to a decrease in $ExpB_t / avgExpB$ over time, such as price, were predicted to have a negative coefficient, whereas variables that were hypothesized to contribute to an increase in $ExpB_t / avgExpB$ were predicted to have a positive coefficient. After analyzing each model, the coefficient estimates were examined to see if they matched the predictions. In addition to the signs (positive or negative) of the coefficients, the R^2 and values of the Akaike Information Criterion (AIC_c) and Schwarz's Bayesian Information Criterion (BIC) were also used as indicators of model performance.

After linear models were analyzed, polynomial and exponential models were also analyzed. It was anticipated that the nonlinear models would perform at least as well as the linear models because they allowed for the possibility of non-linear relationships between the explanatory variables and the dependent variable.

Figure 2 shows how well each tier 3 model represented time series observations on the individual species. Because the models were estimated across species, in some instances, the model fit the overall dataset but did not provide a good fit for the individual species' datasets. For example, a model might overestimate the dependent variable for one species but underestimate it for another and in so doing minimize the sum of squared errors across the whole set of species and time series observations. However, the underlying reasons for applying models that include multiple species were to evaluate more observations with the model, and also to examine the overall effect each parameter has on rockfishes in general rather than an individual rockfish species. A general model of the effects of management and biological characteristics of Alaskan rockfishes should have greater relevance when examining the general influence of these variables on rockfishes.

3. Results

3.1 Tier 3 Models

Linear, polynomial, and exponential formulations of equation (2) were estimated for the system of 5 tier 3 stocks. Goodness-of-fit statistics and coefficient estimates for the linear and polynomial models are presented in Table 10. Table 11 includes goodness-of-fit statistics and coefficient estimates for the exponential models; to facilitate comparison with the linear and polynomial models, the goodness-of-fit statistics reported in Table 11 represent fit to the back-transformed values of $ExpB_t$ / $avgExpB$ rather than to $\ln(ExpB_t / avgExpB)$. Model selection was based on goodness-of-fit (R^2, AIC_c, BIC) for the overall system of 5 stocks, and the sign, magnitude, and statistical significance of each estimated coefficient. In addition, R^2 and F-statistics were calculated to judge the fit of the system models to individual stocks. Table 12 lists the R^2 values, coefficient estimates, and effective observations for each stock for each of the tier 3 models; where the error sum of squares was significantly smaller than the total sum of squares for a particular series, the estimate of R^2 has been bolded.

Model 4 provided a good fit for the overall dataset (lowest BIC and second highest R^2) and for 4 of the 5 stocks: GOA Dusky Rockfish, R^2 = 0.905; GOA Pacific Ocean Perch, R^2 = 0.994; GOA Northern Rockfish, R^2 = 0.887; BSAI Northern Rockfish, R^2 = 0.615; BSAI Pacific Ocean Perch, R^2 = 0.395 (Tables 10 - 12 and Figures 2(a) - (e)). Unfortunately, while Model 4 included 7 coefficients that differ significantly from zero (P > 0.05), several of those coefficients did not make biological sense (Table 10). Models 1 - 3 were rejected because their BIC statistics were inferior to the BIC statistic for Model 4 and because the estimated coefficients of Models 1 - 3 also failed to make biological sense. For example, the parameter *Recruits* has a negative coefficient for Models 1 - 4, which suggests that as the number of recruitments increases, $ExpB_t$ / $avgExpB$ decreases. According to the literature, greater recruitment contributes to higher stock resilience (Myers and Barrowman, 1996).

Model 5 was rejected because the sign of the coefficients for *Catch / ABC* and recruitment did not make sense from a biological perspective (Table 10). According to the Model 5 results, as the number of recruits increases, $ExpB_t$ / $avgExpB$ is expected to decrease, and as *Catch / ABC* increases, $ExpB_t$ / $avgExpB$ is expected to increase. One would not expect biomass to decrease as recruitment increases, or for biomass to increase as the exploitation rate increases. Models 8 and 16 were rejected because their R^2, AIC_c, and BIC statistics were high when compared to the other tier 3 models (Tables 10 - 11). Models 9 and 10 included qualitative variables to denote the

5 stocks in lieu of stock specific life history variables. While these models yielded high values of R^2 and low AIC_c and BIC statistics, they were rejected because they are not as useful for inference about stocks that were not represented in the data used to fit the model (Table 10). We reasoned that it is more informative to include life history parameters that are characteristic of each species in the model, than to include the species themselves because estimates of the influence of life history parameters can be related to un-modeled species that share similar life history parameters. Models 11 - 16 adopted a log-linear functional form rather than the polynomial form adopted in models 1 - 10. Models 11 - 14 were rejected because several of the coefficients had signs that did not make sense from a biological perspective (Table 11).
Model 15 was rejected because it had a relatively low R^2 value, relative high values for AIC_c and BIC and the sign of the coefficient for age at 50% maturity did not make sense from a biological perspective. According to the Model 15 results, as age at 50% maturity increases, $ExpB_t / avgExpB$ is expected to increase. However, the longer it takes to reach maturity, the greater likelihood that a given rockfish stock would succumb to fishing pressure before having an opportunity to reproduce.

Thus by process of elimination, Model 7 was selected as the preferred model for the 5 tier 3 stocks. Model 7 exhibited relatively low AIC_c (-4.762) and BIC (-4.514) values, a relatively high value for R^2 (0.922), and included 8 variables that had statistically significant ($P < 0.01$) coefficients. Model 7 provided a good fit for GOA Dusky Rockfish, ($R^2 = 0.746$), GOA Pacific Ocean Perch ($R^2 = 0.964$), and GOA Northern Rockfish ($R^2 = 0.765$) but failed to provide a statistically significant fit to the time series observations representing BSAI Northern Rockfish or BSAI Pacific Ocean Perch (Table 12). Although Model 7 did not provide a good fit for the BSAI stocks, it was preferable to the other estimated models because the coefficients were consistent with biological and economic relationships observed for other species. The failure to fit observations of the 2 BSAI stocks is likely a consequence of the limited number of observations (8 for BSAI Northern Rockfish and 9 for BSAI Pacific Ocean Perch) and because of the limited variability in observations of the dependent variable over a very short time span.

All of the coefficients in model 7 had signs that were consistent with predictions, and most of these variables were statistically significant: ($P < 0.01$) for the intercept and the coefficients on spawning biomass, the square of spawning biomass, maximum age, and habitat; ($P < 0.05$) for coefficients on *Catch / ExpB*, $(Catch / ExpB)^2$, PDO, and price; and ($P = 0.09$) for the coefficient on growth rate.

The coefficients in Model 7 indicate that a 1 unit increase in the normalized value of spawning biomass leads to an increase of 1.332 in $ExpB_t / avgExpB$, but that the rate of increase decreases at higher levels of spawning biomass because the coefficient on squared spawning biomass is negative. A 1 unit increase in rockfish normalized maximum age leads to a decrease of 0.643 in $ExpB_t / avgExpB$. The results indicate that rockfishes living in rocky biogenic habitat are less prone to over-exploitation: $ExpB_t / avgExpB$ for these species is 1.023 larger than $ExpB_t / avgExpB$ for rockfish species that do not live in rocky biogenic habitat. The model results suggest that a 1 unit increase in the normalized exploitation rate leads to a decrease of 0.146 in $ExpB_t / avgExpB$ but the rate of decrease is moderated by a non-linear effect at higher exploitation rates. Elevated values of the PDO index are associated with decreases in $ExpB_t / avgExpB$; a one-unit increase in the PDO decreases $ExpB_t / avgExpB$ by 0.095. A 1 unit increase in normalized ex-vessel price leads to a decrease of 0.032 in $ExpB_t / avgExpB$ (See Table 10 for coefficient values).

Currently none of the tier 3 stocks included in the study are classified as overfished. However, Northern Rockfish and Dusky Rockfish exploitable biomass in the GOA are both currently below *avgExpB*, the proxy used for B_{MSY}. Dusky Rockfish in the GOA experienced a decline in $ExpB_t$ / *avgExpB* from 2005-2011 and Northern Rockfish experienced a steady decline in $ExpB_t$ / *avgExpB* since the mid-1990s.

3.2 Tier 4/5 Models

A total of 30 models were estimated for the tier 4/5 rockfish species: 15 linear models, 8 exponential models, and 7 quadratic (polynomial) models (Tables 12 - 15). Because the tier 4/5 species lack data for several life history parameters, it was challenging to configure a model that provided good fit to the observations and also yielded coefficient estimates consistent with our predictions, which are based on data from scientific literature. Model 1 and model 2 were eliminated because we wanted to include BSAI Shortspine Thornyhead in the model rather than ABC and *Catch / ABC* (Table 13). Data for ABC and *Catch/ABC* were not available for BSAI Shortspine Thornyheads. In addition, ABC and *Catch / ABC* were not significant ($P > 0.05$) in the models in which they were included. Model 3 failed to solve because age at 50% maturity and maximum age were perfectly collinear ($r = 1$) according to the Pearson's correlation test results. Models 4, 5, and 7 were eliminated because of the inexplicably high magnitude of several coefficients estimated in each of the models (Table 13). The higher the magnitude of the coefficient, the greater effect a given parameter has on the dependent variable. Typically variables contribute to an increase or decrease in the dependent variable by an order of no more than a few units. However, the magnitude of some of the coefficients in Models 4, 5, and 7, such as habitat, length at 50% maturity, and age at 50% maturity, were much higher. Model 6, although it has a low R^2, seemed to be the best choice of these models (Table 13). Several variations of model 6 were analyzed to try to produce a better fitting model (including exponential and quadratic versions of the model) (Tables 14 - 16). The variations of model 6 are listed as 6-2, 6-3, etc. Model 6-4 appears to be the best choice of the models, although not all signs for the coefficients were consistent with predictions (Tables 13 - 16). The R^2 values for the tier 4/5 models, including model 6-4, were relatively low, and few variables were available for the models. There were several limitations from a lack of biological data and from the use of the variable catch, which is very similar to the dependent variable C_t / *avgC*, to explain most of the data. Consequently, a tier 4/5 model was not selected; rather we discuss the lack of data for tier 4/5 rockfish species and the necessity of further research on these species in order to ensure optimal management strategies.

4. Discussion

According to the tier 3 regression analyses, Models 4 and 7 were the best candidates for explaining the data. However, Model 4 had several coefficients whose signs were inconsistent with observed biological and economic relationships, e.g., recruitment, growth rate, age at 50% maturity, price, and *catch / ABC*. In addition, signs of the coefficients for age at 50% maturity and maximum age were opposite of those expected, although one would expect these two variables to exhibit a similar influence on $ExpB_t$ / *avgExpB*. For example it would be expected that if recruitment or growth rate increased, $ExpB_t$ / *avgExpB* would increase. Conversely, if age at 50% maturity, price, and *catch / ABC* increased, it would be expected that $ExpB_t$ / *avgExpB* would decrease. However, the signs of the coefficients for these variables in Model 4 were opposite of expectations. The results for Model 4 also contradict the logical assumption that as *catch / ABC* and price increase, then $ExpB_t$ / *avgExpB* would be expected to decrease because of the increase in fishing pressure and market value, respectively.

Although Model 7 did not fit as well as Model 4, it was more realistic at representing the effects of the explanatory variables. All of the estimated parameters contributed to model fit—dropping any of the included variables resulted in statistically significant reductions in goodness-of-fit. Model 7, included spawning biomass, squared spawning biomass, maximum age, growth rate, $catch/ ExpB_t$, $(catch / ExpB_t)^2$, PDO, habitat, and price; although growth rate was not significant at a 5% level, it was at a 10% level. Model 7 suggested that these parameters have the most influence on trends in Alaskan rockfish exploitable biomass of the variables examined. Fish populations vary because of density-dependent and density-independent processes that affect recruitment, age structure, natural mortality, and growth, as well as from the level of fishing pressure (Sissenwine, 1984). Low spawning biomass may make stocks more vulnerable to becoming overfished. These results are consistent with studies such as that of Myers and Barrowman (1996), which showed that spawning biomass directly affects stock resilience. Since spawning biomass has multiple effects on exploitable biomass both by contributing to recruits and aspects of the overall exploitable biomass, its effects on $ExpB_t$ / $avgExpB$ are non-linear. However, model 7 estimates indicate that as spawning biomass increases, the ratio of $ExpB_t$ / $avgExpB$ would increase. Rockfish stocks that have a relatively low or decreasing spawning biomass may be more vulnerable to becoming overfished. Consequently, it is imperative that spawning biomass estimates be considered when establishing management protocol for rockfish stocks. Further research is necessary to determine spawning biomass estimates for rockfish in tier 4/5. Because information is currently unavailable for tier 4/5 rockfish, they may be at a greater risk of becoming overfished.

The data indicate that long-lived species of rockfish are more vulnerable to overexploitation. These results are consistent with studies that show that long-lived fish are at greater risk of a phenomenon known as longevity overfishing (Beamish et al., 2006). Longevity overfishing refers to overfishing the older fish in a given stock (Beamish et al., 2006). Older fish may be more productive than their younger counterparts because they produce more and larger eggs than younger fish (Hixon et al., 2014). If younger rockfish do not have the same productivity as older fish, a stock that is depleted of older fish would be less likely to recover from overfishing (Beamish et al., 2006). Because current management of rockfish assumes that young reproductively mature rockfish will have the same productivity as older rockfish, they do not consider the risk of longevity overfishing.

Of the species of rockfish considered herein, those that have higher growth rates have been more resilient than those with lower growth rates. This is consistent with Norse et al. (2011) who suggest that slow-growing fish have lower resilience to fishing pressure. In our analysis, growth rate did not have a statistically significant effect on rockfish vulnerability to overfishing. However, as growth rate increases, one could expect this ratio to increase. The growth rate of a rockfish stock is likely to be influenced by numerous factors, such as environmental conditions, food availability, etc.; therefore, the effect of growth rate on the resilience of a rockfish may be difficult to distinguish from the effect of other variables that are related to rockfish growth rate.

Because environmental factors, in addition to life history characteristics, influence the size and resilience of rockfish populations, they can also be expected to affect rockfish vulnerability to becoming overfished. The regression analyses indicate that as the PDO index increases, the ratio of rockfish $ExpB_t$ / $avgExpB$ declines. Richardson and Schoeman (2004) observed that warmer temperatures in the North Atlantic could reduce certain plankton productivity and reduce food availability for planktivorous fish, such as several rockfish species, suggesting that climatic regimes may affect ocean productivity.

Environmental factors, such as the PDO, appear to influence trends in exploitable biomass, as does fishing effort. Results of the model indicate that as the ratio of catch/exploitable biomass increases, the ratio of $ExpB_t$ / *avgExpB* decreases. These results suggest the necessity of maintaining quotas that will allow a recently depleted stock to rebuild. It is imperative that trends in the exploitable biomass and catch of rockfish stocks continue to be closely observed so that annual catch does not exceed a level that would substantially decrease rockfish exploitable biomass.

In addition to large-scale environmental variables such as climate variation, habitat complexity also affects rockfish resilience. According to the estimates of model coefficients, rockfish that inhabit areas with both rocky and biogenic structures have a higher $ExpB_t$ / *avgExpB* ratio than rockfish that inhabit solely rocky substrate. That is, rockfish that live in more complex habitat may have more shelter available and be less likely to be caught. Moreover, Johnson (2007) suggested that rockfish that live in highly complex habitat have higher recruitment and lower mortality than their counterparts living in less sheltered habitat. Complex habitat may provide protection from natural predators, increasing likelihood of survival, particularly during the juvenile stage when rockfish are more susceptible to predation.

According to our analysis, economic factors also appear to affect rockfish exploitable biomass trends significantly. When price increases, the $ExpB_t$ / *avgExpB* ratio decreases. Price can generally be expected to increase as consumer demand increases and/or as supply decreases. As price increases, one would expect an increase in fishing effort and, therefore, as fishing pressure increases because of higher prices, exploitable biomass tends to decline.

The time series of $ExpB_t$ */ avgExpB* showed a decline in exploitable biomass for Dusky Rockfish and Northern Rockfish during recent years. While this does not imply that Northern

Rockfish and Dusky Rockfish in the GOA are at immediate risk of becoming overfished, precaution should be taken to ensure that exploitable biomass levels do not drop below 50% of B_{MSY} proxies (at which point the stock would be considered overfished).

Overall, the results of the analysis suggest that some life history characteristics, environmental factors, and economic factors have a more pronounced effect on the vulnerability of Alaska rockfish to overfishing than other parameters. It is recommended that fisheries managers continue to adjust exploitation rates according to rockfish life histories and environmental and economic trends, and that further research be conducted on rockfish for which these data are limited and/or unavailable.

5. Conclusions

In assessing variables that may influence the vulnerability of rockfish to being overfished, it was observed that several biological characteristics affect tier 3 Alaska rockfish resilience. In particular, spawning biomass, maximum lifespan, and habitat preference significantly affect $ExpB_t$ / $avgExpB$. Although other biological characteristics, particularly those that are related to these variables, may also play a role in rockfish vulnerability to overfishing, the particular variables identified should be given emphasis when establishing management protocols. The analysis also indicated that environmental and economic variables have a significant effect on the vulnerability of tier 3 Alaska rockfish and should be considered when establishing management protocols. However, while the models fit well for the GOA tier 3 species, they did not fit well for the BSAI tier 3 species, perhaps because the BSAI species had very short time series of data available. Thus, it is imperative that surveys on BSAI rockfish stocks continue in the long-term in order for models to better predict the effect of biological, management, environmental, and economic parameters on rockfishes in the BSAI. It may be helpful to use the general model to develop models for individual stocks provided there are enough data available. other rockfish species are likely affected by environmental and economic factors in a similar manner to the species of Alaskan rockfish that were examined.

Rockfish and other fishes that have relatively long lifespans, exhibit low spawning biomass, and live in less sheltered habitat are also likely to be vulnerable to being overfished. However, because of the difficulty in identifying a proxy to determine the level of exploitation of the tier 4/5 rockfish stocks, long-term compilation of biological data is needed for these species to estimate biomass. It would be useful to conduct an analysis that includes species under different management tiers to determine the effect of varying management regimes on rockfish resilience to fishing pressure. It is clear that long-lived species are more vulnerable to becoming overfished, and it is imperative that there be adequate biological, environmental, and economic data available in order to establish effective management and conservation practices.

6. Literature Cited

Alaska Department of Fish and Game (ADF&G).

2012. http://www.adfg.alaska.gov/index.cfm?adfg

Beamish, R. J., G. A. McFarlane, and A. Benson.

2006. Longevity overfishing. Prog. Oceanogr. 68:289-302.

Brodeur, R. D.

2000. Habitat-specific distribution of Pacific ocean perch (*Sebastes alutus*) in Pribilof Canyon, Bering Sea. Cont. Shelf. Res. 21:207-224.

Carlson, H. R., and R. R. Straty.

1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky coastal areas of Southeastern Alaska. Mar. Fish. Rev. 43:13-19.

Chilton, E.

2007. Maturity of female northern rockfish *Sebastes polyspinis* in the Central Gulf of Alaska. Alaska Fish. Res. Bull. 12:264-269.

Clausen, D. M.

2010. Assessment of shortraker rockfish and "other slope rockfish" stocks in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2010 Gulf of Alaska groundfish fishery, p. 551-556. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Clausen D. M., and K. B. Echave.

2011. Assessment of the "other slope rockfish" stock complex in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 1239-1280. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Clausen, D., and J. Heifetz.

2002. The northern rockfish, *Sebastes polyspinis*, in Alaska: commercial fishery, distribution, and biology. Mar. Fish. Rev. 64:1-28.

Clausen D., T. Pearson, and C. Lunsford.

2011. Management reorganization of species in the Gulf of Alaska pelagic shelf rockfish and "other slope rockfish" assemblages. Discussion paper for Gulf of Alaska groundfish plan team, 12 p. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Drake J. S., E. A. Berntson, J. M. Cope, R. G. Gustafson, E. E. Holmes, P. S. Levin, N. Tolimieri, R. S. Waples, S. M. Sogard, and G. D. Williams.

2010. Status review of five rockfish species in Puget Sound, Washington: bocaccio rockfish (*Sebastes paucispinis*), canary rockfish (*S. pinniger*), yelloweye rockfish (*S. ruberrimus*), greenstriped rockfish (*S. elongatus*), and redstripe rockfish (*S. proriger*). NOAA Tech. Memo. NMFS-NWFSC-108. 234 p.

Echave, K. B., and S. K. Shotwell.

2013. Assessment of the “other slope rockfish” stock complex in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2013 Gulf of Alaska groundfish fishery, p. 905-908. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Fissel, B., M. Dalton, R. Felthoven, B. Garber-Yonts, A. Haynie, A. H. Cornel, S. Kasperski, J. Lee, D. Lew, L. Pfeiffer, and C. Seung.

2014. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands area: economic status of the groundfish fisheries off Alaska, 2012, 364 p. [Available from the Alaska Fisheries Science Center, National Marine Fisheries Service, 7600 Sand Point Way N.E. Seattle, Washington 98115-6349.]

Freese, J. L., and B. L. Wing.

2003. Juvenile red rockfish, *Sebastes* sp., associations with sponges in the Gulf of Alaska. Mar. Fish. Rev. 65:38-42.

Gharrett, A. J., A. P. Matala, E. L. Peterson, A. K. Gray, Z. Li, and J. Heifetz.

2007. Distribution and population genetic structure of sibling rougheye rockfish species. *In* Biology, assessment, and management of North Pacific rockfishes (J. Heifetz, J. DiCosimo, A. J. Gharrett, M. S. Love, V. M. O'Connell, and R .D. Stanley, eds.), p. 121-140. Alaska Sea Grant Press, Fairbanks, AK.

Goodman, D., M. Mangel, G. Parkes, T. Quinn, V. Restrepo, T. Smith, and K. Stokes.

2002. Scientific review of the strategy currently used in the BSAI and GOA groundfish fishery management plans, 153 p. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hanselman, D. H., T. J. Quinn, C. Lunsford, J. Heifetz, and D. M. Clausen.

2003. Applications in adaptive cluster sampling of Gulf of Alaska rockfish. Fish. Bull. 101:501–512.

Hanselman, D. H., S. K. Shotwell, P. J. F. Hulson, C. R. Lunsford, and J. Ianelli.

2013. Assessment of the Pacific ocean perch stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2013 Gulf of Alaska groundfish fishery, p. 757-832. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hare, S. R., and N. J. Mantua.

2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47:103-145.

Hawkins, S. L., J. Heifetz, C. M. Kondzela, J. E. Pohl, and R. L. Wilmot.

2005. Genetic variation of rougheye rockfish (*Sebastes aleutianus*) and shortraker rockfish (*Sebastes borealis*) inferred from allozymes. Fish. Bull. 103:524-535.

Hixon, M. A., D. W. Johnson, and S. M. Sogard.

2014. BOFFFs: on the importance of conserving old-growth age structure in fishery populations. ICES J. Mar. Sci. 71:2171-2185. doi: 10.1093/icesjms/fst200

Hulson, P. J. F., J. Heifetz, D. H. Hanselman, S. K. Shotwell, and J. N. Ianelli.

2013. Assessment of the northern rockfish stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2013 Gulf of Alaska groundfish fishery, p. 833-904. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hutchinson, C. E.

2004. Using radioisotopes in the age determination of shortraker (*Sebastes borealis*) and canary (*Sebastes pinniger*) rockfish. M.S. thesis, 204 p. Univ. Washington, Seattle, WA.

Johnson, D. W.

2007. Habitat complexity modifies post-settlement mortality and recruitment dynamics of a marine fish. Ecology 88:1716-1725.

Krieger, K. J.

1992. Shortraker rockfish, *Sebastes borealis*, observed from a manned submersible. Mar. Fish. Rev. 54:34–36.

Krieger, K. J., and D. H. Ito.

1999. Distribution and abundance of shortraker rockfish, *Sebastes borealis,* and rougheye rockfish, *S. aleutianus,* determined from a manned submersible. Fish. Bull. 97:264-272.

Krieger, K. J., and B. L. Wing.

2002. Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. Hydrobiology 471: 83-90.

Love, M. S., M. Yoklavich, and L. Thorsteinson.

2002. The rockfishes of the Northeast Pacific. 405 p. Univ. Calif. Press, Berkeley, CA.

Lowe, S. A., and P. D. Spencer.

2009. Assessment of Bering Sea and Aleutian Islands “other rockfish”. *In* Stock assessment and fishery evaluation report for the 2009 Bering Sea and Aleutian Islands groundfish fishery, p. 975-978. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Lunsford, C. R., D. H. Hanselman, S. K. Shotwell, and D. M. Clausen.

2004. Gulf of Alaska pelagic shelf rockfish. *In* Stock assessment and fishery evaluation report for the 2004 Gulf of Alaska groundfish fishery, p. 465-498. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Lunsford, C. R., S. K. Shotwell, P. F. Hulson, and D. H. Hanselman.

2013. Assessment of dusky rockfish in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2013 Gulf of Alaska groundfish fishery, p. 909-974. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Mantua, N. J., and S. R. Hare.

2002. The Pacific Decadal Oscillation. J. Oceanogr. 58:35-44.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis.

1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol. Soc. 78:1069-1079.

McDermott, S. F.

1994. Reproductive biology of rougheye and shortraker rockfish, *Sebastes aleutianus* and *Sebastes borealis*. M.S. thesis, 76 p. Univ. Washington, Seattle, WA.

Miller, A. K., and W. J. Sydeman.

2004. Rockfish response to low-frequency ocean climate change as revealed by the diet of a marine bird over multiple time scales. Mar. Ecol. Prog. Ser. 281:207-216.

Munk, K. M.

2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and considerations of age determination. Alaska Fish. Res. Bull. 8:1-16.

Murphy, J., and J. Ianelli.

2011. Assessment of the thornyhead stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 1199-1238. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Musick, J. A., M. M. Harbin, S. A. Berkeley, G. H. Burgess, A. M. Eklund, L. Findley, R. G. Gilmore, J. T. Golden, D. S. Ha, G. R. Huntsman, J. C. McGovern, G. R. Sedberry, S. J. Parker, S. G. Poss, E. Sala, T. W. Schmidt, H. Weeks, and S. G. Wright.

2000. Marine, estuarine, and diadromous fish stocks at risk of extinction in North America (exclusive of Pacific Salmonids). Fisheries 25:6-30.

Myers, R. A., and N. J. Barrowman.

1996. Is fish recruitment related to spawner abundance? Fish. Bull. 94:707-724.

National Marine Fisheries Service (NMFS).

1999. Environmental assessment for Amendment 56 to the FMP for the ground fish fishery of the BSAI area and Amendment 56 to the FMP for the groundfish fishery of the GOA—To redefine acceptable biological catch and overfishing, 54 p. NMFS Alaska Fisheries Science Center, Seattle, WA.

Norse, E. A., S. Brooke, W. W. L. Cheung, M. R. Clark, I. Ekland, R. Froese, K. M. Gjerde, R. L. Haedrich, S. S. Heppell, T. Morato, L. E. Morgan, D. Pauly, R. Sumaila, and R. Watson.

2011. Sustainability of deep-sea fisheries. Mar. Policy 36:307-320.

NPFMC (North Pacific Fishery Management Council).

2003. Environmental Assessment/Regulatory Impact Review/ Initial Regulatory Flexibility Analysis for Amendment 77 to the Fishery Management Plan for Bering Sea/Aleutian Islands groundfish: allocation of Pacific Cod among fixed gear sectors, 220 p. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

NPFMC (North Pacific Fishery Management Council).

2011. Fishery management plan for groundfish of the Bering Sea and Aleutian Islands management area. 145 p. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

NPFMC (North Pacific Fishery Management Council).

2013a. Stock assessment and fishery evaluation report for the groundfish fisheries of the Bering Sea/Aleutian Islands area, Nov. 2013. 1092 p. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

NPFMC (North Pacific Fishery Management Council).

2013b. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska, Nov. 2013. 1064 p. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Pauly, D., V. Christiensen, S. Guenette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller.

2002. Towards sustainability in world fisheries. Nature 418:689-695.

Pearson, K. E., and D. R. Gunderson.

2003. Reproductive biology and ecology of shortspine thornyhead rockfish (*Sebastolobus alascanus)* and longspine thornyhead rockfish (*S. altivelis)* from the northeastern Pacific Ocean. Environ. Biol. Fish. 67:11-136.

Reuter, R. F.

1999. Describing dusky rockfish (*Sebastes ciliatus*) habitat in the Gulf of Alaska using historical data. M.S. thesis, 83 p. California State Univ., Hayward, CA.

Richardson, A. J., and D. S. Schoeman.

2004. Climate impact on plankton ecosystems in the Northeast Atlantic. Science 305:1609-1612.

Rooper, C. N., and J. L. Boldt.

2005. Distribution of juvenile Pacific ocean perch *Sebastes alutus* in the Aleutian Islands in relation to benthic habitat. Alaska Fish. Res. Bull. 11:102-112.

Rooper, C. N., J. L. Boldt, and M. Zimmermann.

2007. An assessment of Pacific ocean perch *(Sebastes alutus)* habitat use in a deepwater nursery. Est. Coast. Shelf Sci. 75:371–380.

Shotwell, K. S., J. Ianelli, and J. Heifetz.

2013. Assessment of the thornyhead stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2013 Gulf of Alaska groundfish fishery, p. 997-1000. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Sissenwine, M. P.

1984. Why do fish populations vary? *In* Exploitation of marine communities (R. M. May, ed.), p. 59-94. Springer-Verlag, Berlin.

Spencer, P. D., and J. N. Ianelli.

2012a. Assessment of the northern rockfish stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2012 Bering Sea/Aleutian Islands groundfish fishery, p. 1349-1422. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer, P. D., and J. N. Ianelli.

2012b. Assessment of the Pacific ocean perch stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2012 Bering Sea/Aleutian Islands groundfish fishery, p. 1291-1348. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer, P. D., and J. N. Ianelli.

2013a. Assessment of the northern rockfish stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2013 Bering Sea/Aleutian Islands groundfish fishery, p. 859-864. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer, P. D., and J. N. Ianelli.

2013b. Assessment of the Pacific ocean perch stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2013 Bering Sea/Aleutian Islands groundfish fishery, p. 853-858. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer P. D., and C. N. Rooper.

2012. Assessment of the shortraker rockfish stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2012 Bering Sea/Aleutian Islands groundfish fishery, p. 1497-1530. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spies, I., and P. D. Spencer.

2012. Assessment of the Other Rockfish complex in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2012 Bering Sea/Aleutian Islands groundfish fishery, p. 1531-1560. [Available from the North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spies, I., and P. D. Spencer.

2013. Assessment of the Other Rockfish complex in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2013 Bering Sea/Aleutian Islands groundfish fishery, p. 905-910. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spies, I., P. D. Spencer, and J. N. Ianelli.

2013. Assessment of the shortraker rockfish stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the 2013 Bering Sea/Aleutian Islands groundfish fishery, p. 901-904. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Tribuzio, C., and K. B. Echave.

2013. Assessment of the Other Rockfish stock complex in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2013 Gulf of Alaska groundfish fishery, p. 1001-1028. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Yoklavich, M. M.

1998. Marine harvest refugia for west coast rockfish: a workshop. NOAA Tech. Memo. NMFS-SWFSC-255, 158 p.

Zellner, A.

1962. An efficient method for estimating seemingly unrelated regression and tests for aggregation bias. J. Am. Stat. Assoc. 57:348-368.

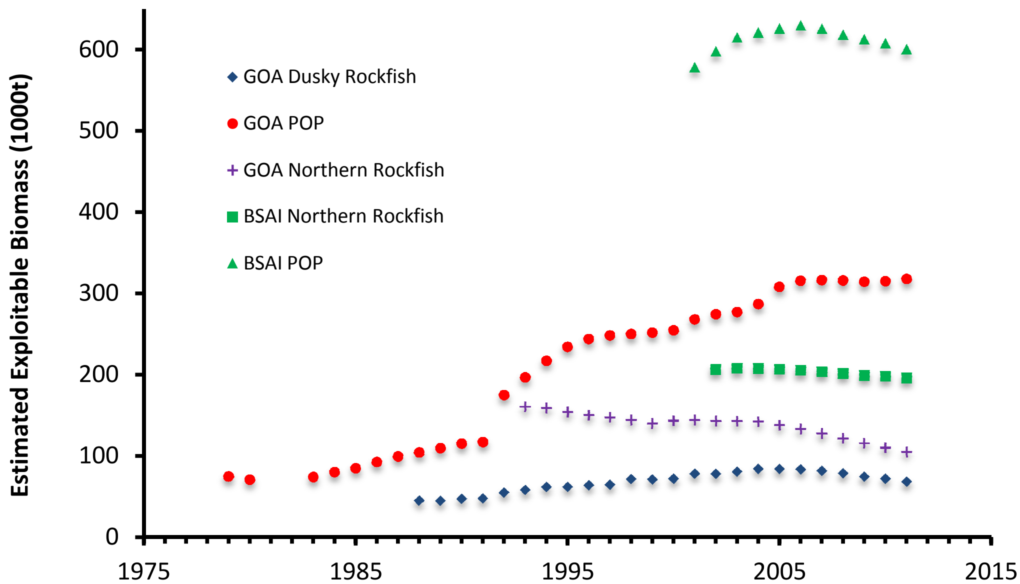

Figure 1. Exploitable biomass estimates (1000s of metric tons) for tier 3 species in the Gulf of Alaska and the Bering Sea/Aleutian Islands during the years 1979-2011.

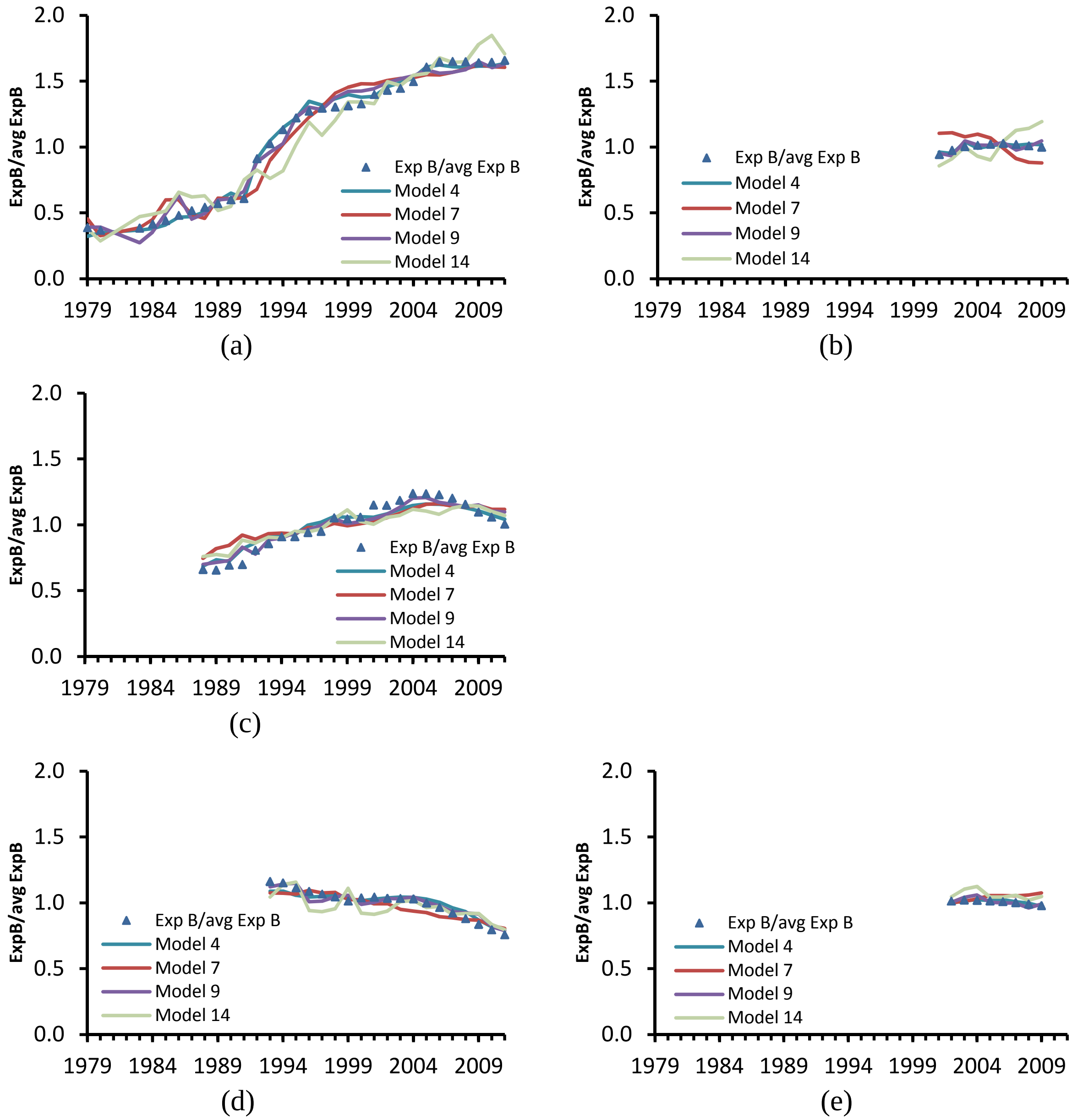

Figure 2. Tier 3 annual exploitable biomass estimates divided by mean exploitable biomass and model estimates.

(a) GOA Pacific Ocean Perch annual exploitable biomass divided by mean (1979-2011) exploitable biomass and model estimates (1979-2011). (b) BSAI Pacific Ocean Perch annual exploitable biomass divided by mean (2001-2011) exploitable biomass and model estimates (2001-2011). (c) GOA Dusky Rockfish annual exploitable biomass divided by mean (1988-2011) exploitable biomass and model estimates (1988-2011). (d) GOA Northern Rockfish annual exploitable biomass divided by mean (1993-2011) exploitable biomass and model estimates (1993-2011). (e) BSAI Northern Rockfish annual exploitable biomass divided by mean (2002-2011) exploitable biomass and model estimates (2002-2011).

Table1. Data sources for BSAI Shortraker Rockfish.

Model parameter	Data source	Parameter modification
Catch (t)	Spencer and Rooper, 2012; Spies et al., 2013	N/A
Acceptable Biological Catch (t)	Spencer and Rooper, 2012; Spies et al., 2013	N/A
Length at 50% maturity (yrs)	Hutchinson, 2004	N/A
Age at 50% maturity (yrs)	McDermott, 1994; Hutchinson, 2004	N/A
Maximum age (yrs)	Munk 2001; Love et al., 2002	N/A
Natural mortality (*M*)	Spencer and Rooper, 2012	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Spencer and Rooper, 2012	Used most recent estimate across the entire time series
Depth (m)	Love et al., 2002	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Krieger and Ito, 1999, Krieger and Wing, 2002	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Spencer and Rooper, 2012; Spies et al., 2013	Indicated as % caught by long-line (remainder caught by trawl)

Table 2. Data sources for GOA Shortraker Rockfish.

Model parameter	Data source	Parameter modification
Catch (t)	Clausen and Echave, 2011; Echave and Shotwell, 2013	N/A
Acceptable Biological Catch (t)	Clausen and Echave, 2011; Echave and Shotwell, 2013	N/A
Length at 50% maturity (yrs)	Hutchinson, 2004	N/A
Age at 50% maturity (yrs)	McDermott, 1994; Hutchinson, 2004	N/A
Maximum age (yrs)	Munk 2001; Love et al., 2002	N/A
Natural mortality (*M*)	Clausen and Echave, 2011	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Clausen and Echave 2011	Used most recent estimate across the entire time series
Depth (m)	Clausen and Echave, 2011	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Krieger, 1992; Krieger and Ito, 1999; Krieger and Wing, 2002; Freese and Wing, 2003	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Clausen and Echave, 2011; Echave and Shotwell, 2013	Indicated as % caught by long-line (remainder caught by trawl)

Table 3. Data sources for BSAI Pacific Ocean Perch.

Model parameter	Data source	Parameter modification
Spawning (age 3+) biomass (t)	Spencer and Ianelli, 2012b; 2013b	N/A
Exploitable (age 3+) biomass (t)	Spencer and Ianelli, 2012b; 2013b	N/A
Catch (t)	Spencer and Ianelli, 2012b; 2013b	N/A
Age 3 recruits (1000s)	Spencer and Ianelli, 2012b; 2013b	N/A
Acceptable Biological Catch (t)	Spencer and Ianelli, 2012b; 2013b	N/A
Length at 50% maturity (yrs)	Spencer and Ianelli, 2012b	N/A
Age at 50% maturity (yrs)	Spencer and Ianelli, 2012b	N/A
Maximum age (yrs)	Spencer and Ianelli, 2012b	N/A
Natural mortality (*M*)	Spencer and Ianelli, 2012b	Used most recent estimate across the entire time series
Intrinsic growth (*k*)	Spencer and Ianelli, 2012b	Used most recent estimate across the entire time series
Depth (m)	Love et al., 2002	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Brodeur, 2000; Love et al., 2002; Rooper and Boldt, 2005; Rooper et al., 2007	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Spencer and Ianelli, 2012b; 2013b	Indicated as % caught by long-line (remainder caught by trawl)

Table 4. Data sources for GOA Pacific Ocean Perch.

Model parameter	Data source	Parameter modification
Spawning (age 6+) biomass (t)	Hanselman et al., 2013	N/A
Exploitable (age 6+) biomass (t)	Hanselman et al., 2013	N/A
Catch (t)	Hanselman et al., 2013	N/A
Age 2 recruits (1000s)	Hanselman et al., 2013	N/A
Acceptable Biological Catch (t)	Hanselman et al., 2013	N/A
Length at 50% maturity (yrs)	Hanselman et al., 2013	N/A
Age at 50% maturity (yrs)	Hanselman et al., 2003	N/A
Maximum age (yrs)	Love et al., 2002; Hanselman et al., 2003	N/A
Natural mortality (*M*)	Hanselman et al., 2013	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Hanselman et al., 2013	Used most recent estimate across the entire time series
Depth (m)	Love et al., 2002	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Carlson and Straty, 1981; Krieger and Wing, 2002; Love et al., 2002; Freese and Wing, 2003	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Hanselman et al., 2013	Indicated as % caught by long-line (remainder caught by trawl)

Table 5. Data sources for BSAI Shortspine Thornyhead.

Model parameter	Data source	Parameter modification
Catch (t)	Spies and Spencer, 2012; 2013	N/A
Acceptable Biological Catch (t)	Spies and Spencer, 2012	N/A
Length at 50% maturity (yrs)	Spies and Spencer, 2012	N/A
Age at 50% maturity (yrs)	Murphy and Ianelli, 2011	N/A
Maximum age (yrs)	Munk, 2001; Love et al., 2002	N/A
Natural mortality (*M*)	Spies and Spencer, 2012	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Spies and Spencer, 2012	Used most recent estimate across the entire time series
Depth (m)	Spies and Spencer, 2012	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Love et al., 2002	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Spies and Spencer, 2012; 2013	Indicated as % caught by long-line (remainder caught by trawl)

Table 6. Data sources for GOA Shortspine Thornyhead.

Model parameter	Data source	Parameter modification
Catch (t)	Murphy and Ianelli, 2011; Shotwell et al., 2013	N/A
Acceptable Biological Catch (t)	Murphy and Ianelli, 2011; Shotwell et al., 2013	N/A
Length at 50% maturity (yrs)	Pearson and Gunderson, 2003	N/A
Age at 50% maturity (yrs)	Murphy and Ianelli, 2011	N/A
Maximum age (yrs)	Love et al., 2002; Murphy and Ianelli, 2011	N/A
Natural mortality (*M*)	Murphy and Ianelli, 2011	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Murphy and Ianelli, 2011	Used most recent estimate across the entire time series
Depth (m)	Love et al., 2002	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Love et al., 2002	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Murphy and Ianelli, 2011; Shotwell et al., 2013	Indicated as % caught by long-line (remainder caught by trawl)

Table 7. Data sources for BSAI Northern Rockfish.

Model parameter	Data source	Parameter modification
Spawning (age 3+) biomass (t)	Spencer and Ianelli, 2012a; 2013a	N/A
Exploitable (age 3+) biomass (t)	Spencer and Ianelli, 2012a; 2013a	N/A
Catch (t)	Spencer and Ianelli, 2012a; 2013a	N/A
Age 3 recruits (1000s)	Spencer and Ianelli, 2012a; 2013a	N/A
Acceptable Biological Catch (t)	Spencer and Ianelli, 2012a; 2013a	N/A
Length at 50% maturity (yrs)	Spencer and Ianelli, 2012a	N/A
Age at 50% maturity (yrs)	Spencer and Ianelli, 2012a	N/A
Maximum age (yrs)	Spencer and Ianelli, 2012a	N/A
Natural mortality (*M*)	Spencer and Ianelli, 2012a	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Spencer and Ianelli, 2012a	Used most recent estimate across the entire time series
Depth (m)	Love et al., 2002	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Krieger, 1992; Freese and Wing, 2003; Spencer and Ianelli, 2013a	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Spencer and Ianelli, 2012a; 2013a	Indicated as % caught by long-line (remainder caught by trawl)

Table 8. Data sources for GOA Northern Rockfish.

Model parameter	Data source	Parameter modification
Spawning (age 6+) biomass (t)	Hulson et al., 2013	N/A
Exploitable (age 6+) biomass (t)	Hulson et al., 2013	N/A
Catch (t)	Hulson et al., 2013	N/A
Age 2 recruits (1000s)	Hulson et al., 2013	N/A
Acceptable Biological Catch (t)	Hulson et al., 2013	N/A
Length at 50% maturity (yrs)	Hulson et al., 2013	N/A
Age at 50% maturity (yrs)	Chilton, 2007: Hulson et al., 2013	N/A
Maximum age (yrs)	Hulson et al., 2013	N/A
Natural mortality (*M*)	Hulson et al., 2013	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Hulson et al., 2013	Used most recent estimate across the entire time series
Depth (m)	Clausen and Heifetz, 2002	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Carlson and Straty, 1981; Krieger and Wing, 2002; Freese and Wing, 2003	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Hulson et al., 2013	Indicated as % caught by long-line (remainder caught by trawl)

Table 9. Data sources for GOA Dusky Rockfish.

Model parameter	Data source	Parameter modification
Spawning (age 4+) biomass (t)	Lunsford et al., 2013	N/A
Exploitable (age 4+) biomass (t)	Lunsford et al., 2013	N/A
Catch (t)	Lunsford et al., 2013	N/A
Age 4 recruits (1000s)	Lunsford et al., 2013	N/A
Acceptable Biological Catch (t)	Lunsford et al., 2013	N/A
Length at 50% maturity (yrs)	Lunsford et al., 2013	N/A
Age at 50% maturity (yrs)	Lunsford et al., 2013	N/A
Maximum age (yrs)	Love et al., 2002; Lunsford et al., 2013	N/A
Natural mortality (*M*)	Lunsford et al., 2013	Used most recent estimate across the entire time series
Growth coefficient (*k*)	Lunsford et al., 2013	Used most recent estimate across the entire time series
Depth (m)	Reuter, 1999	Transformed to qualitative variable based on 2 categories: 0-200 m=0 201-500 m=1
Habitat	Reuter, 1999	Transformed to qualitative variable based on 2 categories: Rocky/biogenic=1 Rocky=0
Pacific Decadal Oscillation	http://jisao.washington.edu/pdo	Mean of May-Oct indices
Inflation-adjusted exvessel prices	Jennifer Shriver, pers. comm., 2013, ADF&G	N/A
Gear type	Lunsford et al., 2013	Indicated as % caught by long-line (remainder caught by trawl)

Table 10. Tier 3 Model statistics, Models 1 – 10.

These summary statistics are derived from a simultaneous equation system estimated by a Seemingly Unrelated Regression (SUR) method applied to normalized annual data (1979 - 2011) for 3 rockfish species (Pacific Ocean Perch, Dusky Rockfish, and Northern Rockfish) managed under tier 3 of the GOA and BSAI groundfish fisheries management plans. The dependent variable for these regressions is annual exploitable biomass divided by average (1979 - 2011) exploitable biomass. Bold values denote coefficients with probabilities less than 1%; bold italic values denote coefficients with probabilities between 1% and 5%.

	Model				
Statistic / Parameter	**1**	**2**	**3**	**4**	**5**
F-statistic	**195.794**	**160.421**	**193.376**	**211.318**	**111.962**
$MSE^{1/2}$	0.045	0.053	0.047	0.046	0.066
CV Regression	4.423	5.133	4.563	4.485	6.465
R^2	0.982	0.976	0.981	0.981	0.960
Akaike Information Criterion	-6.005	-5.723	-5.951	-5.993	-5.278
Bayesian Information Criterion	-3.699	-4.685	-5.426	-5.496	-4.837
Intercept	0.089	0.089	0.078	0.017	0.174
Spawning Biomass	0.108	0.177	0.119	0.161	**1.044**
(Spawning Biomass)^2	0.011	-0.026	0.011	-0.047	**-0.520**
Exploitable Biomass	**1.004**	**1.078**	**0.991**	**1.106**	0
(Exploitable Biomass)^2	**-0.623**	**-0.668**	**-0.582**	**-0.695**	0
Catch/ExpB	-0.197	-0.075	-0.170	-0.052	**-0.293**
(Catch/ExpB)^2	***0.214***	0.096	***0.192***	0.085	**0.303**
Recruitment	**-0.079**	***-0.076***	**-0.081**	**-0.079**	**-0.104**
Recruitment^2	**0.077**	***0.068***	**0.076**	**0.066**	**0.089**
Catch	0.169	0.035	0.131	0	0
Catch^2	-0.135	-0.047	-0.111	0	0
Acceptable Biological Catch (ABC)	0	0	0	0	0
ABC^2	0	0	0	0	0
Catch/ABC	0.050	0.078	0.055	0.029	**0.134**
(Catch/ABC)^2	-0.042	-0.066	-0.043	-0.020	-0.081
Mature Length	0	0	0	0	0
Mature Age	**1.151**	**1.156**	**1.244**	**1.132**	**1.005**
max age	**-2.374**	**-2.391**	**-2.471**	**-2.424**	**-2.025**
Natural Mortality	0	0	0	0	0
Growth Rate	**-1.425**	**-1.426**	**-1.522**	**-1.443**	**-1.095**
Habitat	**1.895**	**1.919**	**1.917**	**2.026**	**1.798**
Pacific Decadal Oscillation	***-0.084***	-0.021	-0.065	**-0.092**	**-0.142**
years >1996	**0.151**	0	**0.078**	**0.164**	0.103
price ($/lb)	***-0.020***	0	***-0.019***	-0.012	***-0.028***
price interaction	***0.182***	***-0.110***	0	***0.168***	0.127
GOA Pacific Ocean Perch	0	0	0	0	0
GOA Northern Rockfish	0	0	0	0	0
BSAI Northern Rockfish	0	0	0	0	0
BSAI Pacific Ocean Perch	0	0	0	0	0

Table 10 (cont.)

	Model				
Statistic / Parameter	**6**	**7**	**8**	**9**	**10**
F-statistic	**125.448**	**107.109**	**38.013**	**132.62**	**111.8757**
$MSE^{1/2}$	0.067	0.089	0.154	0.058	0.083
CV Regression	6.523	8.638	14.945	5.631	8.065
R^2	0.959	0.922	0.762	0.971	0.933
Akaike Information Criterion	-5.277	-4.762	-3.685	-5.538	-4.890
Bayesian Information Criterion	-4.891	-4.514	-3.492	-5.041	-4.614
Intercept	0.230	**0.558**	**1.726**	**1.672**	**1.609**
Spawning Biomass	**1.051**	**1.332**	**0.527**	**0.662**	**1.191**
$(\text{Spawning Biomass})^2$	**-0.518**	**-0.995**	0	*-0.312*	**-0.703**
Exploitable Biomass	0	0	0	0	0
$(\text{Exploitable Biomass})^2$	0	0	0	0	0
Catch/ExpB	**-0.299**	***-0.146***	-0.050	**-0.721**	**-0.179**
$(\text{Catch/ExpB})^2$	**0.305**	***0.159***	0	**0.619**	**0.196**
Recruitment	**-0.108**	0	0	**-0.104**	0
Recruitment^2	**0.094**	0	0	**0.106**	0
Catch	0	0	0	0.249	0
Catch^2	0	0	0	-0.230	0
Acceptable Biological Catch (ABC)	0	0	0	0.171	0
ABC^2	0	0	0	-0.016	0
Catch/ABC	**0.162**	0	0	**0.241**	0
$(\text{Catch/ABC})^2$	***-0.110***	0	0	***-0.124***	0
Mature Length	0	0	0	0	0
Mature Age	**0.987**	0	0	0	0
max age	**-1.969**	**-0.643**	**0.937**	0	0
Natural Mortality	0	0	0	0	0
Growth Rate	***-1.054***	0.123	**0.797**	0	0
Habitat	**1.731**	**1.023**	**-1.551**	0	0
Pacific Decadal Oscillation	***-0.085***	***-0.095***	0.042	**-0.083**	***-0.096***
years >1996	0	0	0	0	0
price ($/lb)	**-0.034**	***-0.032***	**-0.064**	**-0.046**	**-0.034**
price interaction	0	0	0	0	0
GOA Pacific Ocean Perch	0	0	0	**-0.578**	**-0.503**
GOA Northern Rockfish	0	0	0	**-0.646**	**-0.579**
BSAI Northern Rockfish	0	0	0	**-0.943**	**-1.011**
BSAI Pacific Ocean Perch	0	0	0	**-1.901**	**-1.633**

Table 11. Tier 3 Model statistics, Models 11 – 16.

These summary statistics are derived from a simultaneous equation system estimated by a Seemingly Unrelated Regression (SUR) method applied to normalized annual data (1979 - 2011) for 3 rockfish species (Pacific Ocean Perch, Dusky Rockfish, and Northern Rockfish) managed under tier 3 of the GOA and BSAI groundfish fisheries management plans. The dependent variable for these regressions is the natural logarithm of annual Exploitable Biomass divided by mean (1979 - 2011) of the natural logarithm of Exploitable Biomass. Bold values denote coefficients with probabilities less than 1%; bold italic values denote coefficients with probabilities between 1% and 5%.

Statistic /	**Model**					
Parameter	**11**	**12**	**13**	**14**	**15**	**16**
F-statistic	**38.362**	**117.3548**	**63.264**	**64.508**	**47.436**	**34.917**
$MSE^{1/2}$	0.102	0.070	0.115	0.119	0.157	0.187
CV Regression	-441.060	-304.655	-497.693	-514.508	-680.044	-808.687
R^2	0.933	0.965	0.898	0.890	0.800	0.714
Akaike Information Criterion	-4.361	-5.154	-4.225	-4.168	-3.640	-3.303
Bayesian Information Criterion	-3.699	-4.685	-3.922	-3.892	-3.446	-3.137
Intercept	-0.130	-1.392	**-0.087**	-0.036	-0.0047	-0.045
Spawning Biomass	-0.032	-0.161	**0.598**	**0.634**	**0.762**	**0.558**
$(\text{Spawning Biomass})^2$	0.163	0	0	0	0	0
Exploitable Biomass	**1.500**	**1.066**	0	0	0	0
$(\text{Exploitable Biomass})^2$	**-1.094**	0	0	0	0	0
Cat/ExpB	-0.246	0.015	**-0.1690**	**-0.1652**	0	0
$(\text{Cat/ExpB})^2$	0.289	0	0	0	0	0
Recruitment	-0.044	-0.008	***-0.038***	-0.035	0.030	-0.013
Recruitment^2	0.043	0	0	0	0	0
Catch	-0.268	0.005	0.089	0.075	0	0
Catch^2	0.085	0	0	0	0	0
Acceptable Biological Catch (ABC)	0.226	-0.038	0	0	0	0
ABC^2	-0.097	0	0	0	0	0
Catch/ABC	0.187	0.037	**0.114**	**0.118**	0	0
$(\text{Catch/ABC})^2$	-0.062	0	0	0	0	0
Mature Length	-0.238	-1.642	0	0	0	0
Mature Age	-0.044	-0.108	**0.873**	**0.914**	**1.082**	**0.372**
max age	-0.414	-2.556	**-0.939**	**-0.984**	**-1.166**	**-0.393**
Natural Mortality	-0.018	-0.645	0	0	0	0
Growth Rate	0.573	1.529	**-0.542**	**-0.579**	**-0.775**	0
Habitat	0.222	2.706	0	0	0	0
Pacific Decadal Oscillation	-0.070	-0.087	***-0.124***	-0.060	-0.110	0.045
years >1996	0.132	***0.151***	0	0	0	0
Price	-0.024	-0.012	-0.017	***-0.034***	**-0.070**	**-0.107**
price interaction	0.133	0.031	***-0.275***	0	0	0

Table 12. Tier 3 Model statistics, goodness of fit for individual stocks.

Goodness of fit (R^2) statistics for 5 rockfish stocks (GOA Dusky Rockfish, GOA Pacific Ocean Perch, GOA Northern Rockfish, BSAI Northern Rockfish, BSAI Pacific Ocean Perch). These statistics are derived from a simultaneous equation system estimated by a Seemingly Unrelated Regression (SUR) method applied to normalized annual data (1979 - 2011). The dependent variable for Models 1 - 10 was annual exploitable biomass divided by average (1979 - 2011) exploitable biomass. The dependent variable for Models 11 - 16 was the natural logarithm of annual Exploitable Biomass divided by mean (1979 - 2011) of the natural logarithm of Exploitable Biomass. Bolded values denote stocks for which the fit of the model estimates is statistically superior (probabilities less than 1%) to predictions based on the mean; bold italicized values denote instances where the probabilities are between 1% and 5%.

	Coefficients in equation system	**GOA Dusky Rockfish**	**GOA Pacific Ocean Perch**	**GOA Northern Rockfish**	**BSAI Northern Rockfish**	**BSAI Pacific Ocean Perch**
Observations		24	31	19	8	9
Model 1	21	**0.916**	**0.993**	**0.900**	0.560	0.287
Model 2	19	**0.860**	**0.992**	**0.919**	<0	<0
Model 3	20	**0.909**	**0.993**	**0.900**	0.043	<0
Model 4	19	**0.905**	**0.994**	**0.887**	***0.615***	0.395
Model 5	18	**0.856**	**0.977**	**0.858**	<0	<0
Model 6	17	**0.842**	**0.977**	**0.863**	<0	<0
Model 7	10	**0.746**	**0.964**	**0.765**	<0	<0
Model 8	8	**0.592**	**0.903**	<0	<0	<0
Model 9	19	**0.914**	**0.982**	**0.877**	<0	<0
Model 10	11	**0.727**	**0.964**	**0.819**	<0	<0
Model 11	25	**0.770**	**0.899**	**0.893**	0.488	<0
Model 12	18	**0.852**	**0.980**	**0.803**	<0	<0
Model 13	13	**0.823**	**0.929**	**0.517**	<0	<0
Model 14	11	**0.774**	**0.935**	***0.451***	<0	<0
Model 15	8	**0.639**	**0.902**	0.076	<0	<0
Model 16	7	**0.553**	**0.873**	<0	<0	<0

Table 13. Tier 4/5 Model statistics, Models 1 – 7.

These summary statistics are derived from a simultaneous equation system estimated by a Seemingly Unrelated Regression (SUR) method applied to normalized annual data (1991 - 2011) for 2 rockfish species (Shortraker Rockfish and Shortspine Thornyhead) managed under tier 4 and tier 5 of the GOA and BSAI groundfish fisheries management plans. The dependent variable for these regressions is annual catch divided by average (1991 - 2011) catch. Bold values denote coefficients with probabilities less than 1%; bold italic values denote coefficients with probabilities between 1% and 5%.

Statistic /	Model						
Parameter	1	2	3	4	5	6	7
R^2	0.721	0.721	0.663	0.663	0.663	0.487	0.663
SSE	12.465	12.465	15.423	15.423	15.423	23.497	15.423
Akaike Information Criterion	0.001	0.001	0.157	0.157	0.157	0.524	0.157
Intercept	0.554	0.550	1.020	**21.528**	**-29.062**	-1.159	1.020
Catch	**1.129**	**1.129**	**1.003**	**1.003**	**1.003**	**0.798**	**1.003**
Catch^2	0	0	0	0	0	0	0
Max Age	0	0.215	**-23.371**	0	0	**0.487**	0
Gear Type	-2.005	-2.005	-1.756	-1.756	-1.756	2.983	***-1.756***
Pacific Decadal Oscillation	0.464	0.464	-0.286	-0.286	-0.286	-0.968	-0.286
Price	-0.188	-0.188	-0.141	-0.141	-0.141	0.114	-0.141
Acceptable Biological Catch (ABC)	-0.658	-0.658	0	0	0	0	0
Catch/ABC	-0.003	-0.003	0	0	0	0	0
Mature Length	0	0	**0**	**0**	**-33.835**	**0**	**0**
Mature Age	0.212	0	**23.842**	**23.842**	**0**	**0**	**23.842**
Growth Rate	0	0	0	0	0	0	**-23.371**
Habitat	0	0	0	**-46.609**	**68.367**	0	0

Table 14. Tier 4/5 Model statistics, Models 6-2 – 6-7.

These summary statistics are derived from a simultaneous equation system estimated by a Seemingly Unrelated Regression (SUR) method applied to normalized annual data (1991 - 2011) for 2 rockfish species (Shortraker Rockfish and Shortspine Thornyhead) managed under tier 4 and tier 5 of the GOA and BSAI groundfish fisheries management plans. The dependent variable for these regressions is annual catch divided by average (1991 - 2011) catch. Bold values denote coefficients with probabilities less than 1%; bold italic values denote coefficients with probabilities between 1% and 5%.

Statistic /	Model					
Parameter	6-2	6-3	6-4	6-5	6-6	6-7
R^2	0.423	0.455	0.478	0.410	0.392	0.442
SSE	26.390	24.948	23.875	26.986	27.824	25.517
Akaike Information Criterion	0.588	0.532	0.488	0.611	0.592	0.505
Intercept	0.216	-1.254	***-1.298***	-0.024	0.244	***-1.433***
Catch	**0.625**	**0.898**	**0.787**	**0.713**	**0.562**	**0.891**
$Catch^2$						
Max Age	0.218	***0.415***	0.557	0.204	***0.299***	0.496
Gear Type		2.409	**3.315**			***2.779***
Pacific Decadal Oscillation	-0.597		-1.023		-0.626	
Price	0.211	0.139		0.215		
Acceptable Biological Catch (ABC)						
Catch/ABC						
Mature Length						
Mature Age						
Growth Rate						
Habitat						

Table 15. Tier 4/5 Model statistics, Models 6 – 6-8.

These summary statistics are derived from a simultaneous equation system estimated by a Seemingly Unrelated Regression (SUR) method applied to normalized annual data (1991 - 2011) for 2 rockfish species (Shortraker Rockfish and Shortspine Thornyhead) managed under tier 4 and tier 5 of the GOA and BSAI groundfish fisheries management plans. The dependent variable for these regressions is natural logarithm of annual catch divided by average (1991 - 2011) annual catch. Bold values denote coefficients with probabilities less than 1%; bold italic values denote coefficients with probabilities between 1% and 5%.

Statistic /	Model							
Parameter	6	6-2	6-3	6-4	6-5	6-6	6-7	6-8
R^2	0.423	0.369	0.375	0.416	0.343	0.341	0.363	0.314
SSE	2.570	2.810	2.783	2.604	2.926	2.934	2.839	3.058
Akaike Information Criterion	-1.689	-1.652	-1.661	-1.728	-1.611	-1.658	-1.691	-1.664
Intercept	-0.338	0.058	-0.375	-0.380	-0.048	0.066	***-0.431***	-0.043
Catch	**0.214**	**0.164**	**0.253**	**0.211**	**0.204**	**0.146**	**0.250**	**0.186**
Catch^2								
Max Age	***0.137***	0.060	0.109	***0.158***	0.054	***0.083***	**0.135**	0.078
Gear Type	*0.859*		0.639	*0.958*			0.756	
Pacific Decadal Oscillation	-0.371	-0.264		***-0.387***		-0.272		
Price	0.034	0.062	0.044		0.064			
Acceptable Biological Catch (ABC)								
Catch/ABC								
Mature Length								
Mature Age								
Growth Rate								
Habitat								

Table 16. Tier 4/5 Model statistics, Models 6-2 – 6-8.

These summary statistics are derived from a simultaneous equation system estimated by a Seemingly Unrelated Regression (SUR) method applied to normalized annual data (1991 - 2011) for 2 rockfish species (Shortraker Rockfish and Shortspine Thornyhead) managed under tier 4 and tier 5 of the GOA and BSAI groundfish fisheries management plans. The dependent variable for these regressions is annual catch divided by average (1991 - 2011) catch. Bold values denote coefficients with probabilities less than 1%; bold italic values denote coefficients with probabilities between 1% and 5%.

Statistic / Parameter	Model 6-2	6-3	6-4	6-5	6-6	6-7	6-8
R^2	0.429	0.375	0.485	0.416	0.398	0.450	0.384
SSE	2.603	2.783	2.345	2.660	2.743	2.506	2.805
Akaike Information Criterion	-1.728	-1.661	-1.832	-1.707	-1.725	-1.816	-1.750
Intercept	**1.070**	-0.375	**0.590**	**0.996**	**1.079**	**0.547**	**1.001**
Catch	**0.199**	**0.253**	**0.251**	**0.227**	**0.180**	**0.284**	**0.208**
Catch^2							
Max Age	0.067	0.109	**0.174**	0.063	***0.092***	**0.155**	***0.088***
Gear Type		0.639	**1.052**			***0.884***	
Pacific Decadal Oscillation	-0.185		-0.320		-0.193		
Price	0.066	0.044		0.067			
Acceptable Biological Catch (ABC)							
Catch/ABC							
Mature Length							
Mature Age							
Growth Rate							
Habitat							

7. Appendix—Species Profiles

7.1 Shortspine Thornyhead

7.1.1 Life History

7.1.1.1 Morphology and Distribution

The Shortspine Thornyhead (*Sebastolobus alascanus*) is a bright pink, large-eyed demersal fish of the family Scorpaenidae. It is one of three species in the genus *Sebastolobus* (Haldorson and Krieger, 2002). Shortspine Thornyheads are found in depths from 17-1524 m but are most abundant between depths of 150 – 400 m. They range from the Kuril Islands to southern California. Shortspine Thornyheads appear to prefer cooler, deeper waters, and are typically found at greater depths in warmer waters of their range (Gaichas and Ianelli, 2003). Thornyheads have more dorsal spines than *Sebastes* species and lack a swim bladder (Eschmeyer et al., 1983; Nelson, 1994). Shortspine Thornyheads are characterized by a bony extension along their cheek, known as a suborbital stay (Gaichas and Ianelli, 2003).

7.1.1.2 Trophic Interactions

Shrimp comprise the majority of the diet of Shortspine Thornyheads (Murphy and Ianelli, 2011). Other prey species reported in Shortspine Thornyhead stomach content analyses include small fish, crabs, zooplankton, amphipods, and other benthic invertebrates. Juveniles and adults have similar diets, though the juveniles eat a higher proportion of invertebrates (Murphy and Ianelli, 2011).

Adult Shortspine Thornyheads are the primary predator of juvenile Shortspine Thornyheads. In addition, Shortspine Thornyheads are prey for Arrowtooth Flounder (*Atheresthes stomias*), Sablefish (*Anoplopoma fimbria*), Sperm whales, and sharks. However, Shortspine Thornyheads are an uncommon prey in the Gulf of Alaska where they generally make up less than 2% of the primary diets of their predators (Murphy and Ianelli, 2011).

7.1.1.3 Age

Maximum age and natural mortality are closely correlated; longer-lived species typically have a lower natural mortality rate. Accurate natural mortality rates can be estimated if there are sufficient data on the age distribution of a particular species. If data are available for natural mortality estimates, those values can be used to help estimate maximum age, and vice versa. There are few data on age, growth, and natural mortality for Shortspine Thornyheads because they are very difficult to age (Murphy and Ianelli, 2011).

The studies that attempted to estimate maximum age of Shortspine Thornyhead reported a broad range of maximum ages and natural mortalities. Estimates of maximum age range from 62 - 313 years, and natural mortality estimates range from 0.027 - 0.07, depending on the estimation technique used. Miller (1985) estimated a natural mortality for Shortspine Thornyheads of 0.07 and used that estimate to calculate the maximum age of Shortspine Thornyheads as 62 years. However, studies of Shortspine Thornyheads on the west coast of North America reported two maximum age estimates for Shortspine Thornyhead, 115 and 150 years old (Kline, 1996). These higher maximum ages are consistent with natural mortality rates that range from 0.027 to 0.036 (Murphy and Ianelli, 2011). More recent radiometric analyses suggest that the maximum is between 50 - 100 years (Kastelle et al., 2000; Cailliet et al., 2001). However, there is a large variance for these estimates (Murphy and Ianelli, 2011). Other recent analysis of reproductive data for Shortspine Thornyheads in Alaska waters suggests that they are very long-lived, possibly reaching maximum ages between 250 - 313 years (Pearson and Gunderson, 2003). This estimate, obtained from data on the gonosomatic index (the gonad mass in proportion to total body mass of a fish) and natural mortality, was consistent with natural mortality rates (*M*) between 0.013 - 0.015 (Gunderson, 1997). However, these estimates may be high and may therefore predict natural mortality estimates that are too low.

Several recent studies which estimated maximum age to be between 85 - 150 years, consistent with $M = 0.03$ (Murphy and Ianelli, 2011). Until more data are available for Shortspine Thornyhead in the Gulf of Alaska, $M = 0.03$ will be used as the value for natural mortality (Murphy and Ianelli, 2011). However, it is important that a more definitive natural mortality estimate for Shortspine Thornyhead be obtained to effectively manage and conserve the stock. If the natural mortality estimate is inaccurate, the productivity of Shortspine Thornyhead stocks may be over- or underestimated.

7.1.1.4 Reproduction

Shortspine Thornyheads belong to the family Scorpaenidae, which includes rockfish. Scorpaenids are characterized by venomous spines and by internal fertilization of their eggs. Shortspine Thornyheads are distinguished from “true” rockfish by their reproductive biology; whereas species of the genus *Sebastes* are viviparous (giving live birth); thornyheads are oviparous and release fertilized eggs (Eschmeyer et al., 1983; Nelson, 1994; Love et al., 2002). In Alaskan waters, Shortspine Thornyheads reach 50% maturity at about 21.5 cm fork length—approximately 12 years (Pearson and Gunderson, 2003). Females are larger than males, and reach a maximum size of 80 cm (Murphy and Ianelli, 2011). In Alaska, parturition occurs between April and July (Cooper et al., 2005). Shortspine Thornyheads have a maximum fecundity of 1.5 – 2 million eggs (Cooper et al., 2005).

7.1.1.5 Larval and Juvenile Stages

Shortspine Thornyheads are pelagic for the first 14 - 15 months of their lives (Love et al., 2002). They first settle into benthic habitats once they have reached 4 – 6 cm in length (Love, 1996). Juveniles typically settle at depths ranging between 100 m and 600 m and gradually migrating to deeper waters as they grow into adults (Love et al., 2002).

7.1.1.6 Habitat Preferences

Shortspine Thornyheads appear to prefer muddy substrate, occasionally near rocks or gravel. They are typically found resting in small depressions in the substrate. They are solitary and tend to distribute themselves evenly across this habitat (Love et al., 2002). Shortspine Thornyheads inhabit a range of slopes, from steep slopes with numerous boulders to gradual muddy slopes with few boulders (Krieger, 1992; Krieger and Ito, 1999).

7.1.2 Management

7.1.2.1 Historical and Current Fisheries

During the mid-1960s, fleets from the Soviet Union, Japan, and Korea began to target demersal fish, including thornyheads, in Alaska waters (Chitwood, 1969). Shortspine Thornyheads were taken with both longline and trawl gear. They are one of the most valuable rockfish species. Most of the catch of Shortspine Thornyheads is exported to Japan. However, there is no directed fishery for Shortspine Thornyheads because the annual quota is met in bycatch from Sablefish and other rockfish fisheries (Murphy and Ianelli, 2011).

In 1977, thornyheads in Alaska waters were managed with all other Alaskan rockfish except for Pacific Ocean Perch (Berger et al., 1986). In 1980, thornyheads were removed from this group to be managed under a thornyhead species complex, which included Shortspine Thornyhead, Longspine Thornyhead (*Sebastolobus altivelis*), and Broadfin Thornyhead

(*Sebastolobus macrochir*) (Murphy and Ianelli, 2011). Broadfin Thornyhead have not been reported in the GOA and are uncommon in the BSAI. Longspine Thornyheads are uncommon in the GOA and occur in deeper water than Shortspine Thornyheads (Murphy and Ianelli, 2011). The GOA thornyhead stock assessments have primarily focused on Shortspine Thornyheads. Shortspine Thornyheads in the GOA have been managed as a single stock since 1980 (Murphy and Ianelli, 2011*)*.

From 1980 through 1990, ABCs for Shortspine Thornyheads were set at the estimate of maximum sustainable yield, which was 3.8% of the 1987 estimated GOA Shortspine Thornyhead biomass. Estimated biomass declined in the GOA in 1991. Since 2000, the North Pacific Fishery Management Council has set relatively low TACs for GOA Shortspine Thornyheads because of the uncertainty in assessment model results. This uncertainty has been attributed to the lack of data on age and growth. In 2003, the use of the assessment model was suspended and thornyheads were placed in tier 5, resulting in smaller ABCs and TACs. However, the added conservatism in Shortspine Thornyhead management does not appear to have substantially restricted fisheries.

Shortspine Thornyheads in the BSAI are managed as a separate stock from GOA Shortspine Thornyheads. In the BSAI FMP, all thornyhead species are managed within the “other rockfish” species complex (Reuter and Spencer, 2006). Because of lack of biological data, Shortspine Thornyheads in the BSAI are managed under tier 5.

7.1.2.2 Catch Trends

Observed fluctuations in catches of Shortspine Thornyhead appear to result from management actions rather than from changes in thornyhead biomass (Murphy and Ianelli, 2011). Between 1977 and 1983, catches averaged 1090 t in the GOA (Murphy and Ianelli, 2011).

These catches were primarily taken by foreign fleets. Thornyhead catches in the GOA declined in 1984 and 1985 as a result of restrictions placed on foreign fisheries. In 1985, U.S. domestic catch surpassed foreign catch, and domestic catch continued to increase in the late 1980s, reaching a peak of 2616 t in 1989 (Murphy and Ianelli, 2011). Catches averaged 1340 t annually between 1990 and 2003. Catches have averaged 715 t between 2004 and 2011 (Murphy and Ianelli, 2011). Up to 88% of Shortspine Thornyhead catch has been retained since 2005. The decline in catch over recent years has been attributed to a decrease in Shortspine Thornyhead catches in the deep-water flatfish fisheries. Conversely, catches in the Sablefish and rockfish fisheries have remained stable.

7.1.2.3 Incidental Catch

There are no records of Shortspine Thornyhead discards prior to 1990. It was assumed that the reported catches before 1990 included both retained and discarded catch (Murphy and Ianelli, 2011). The directed fishery for Sablefish harvested the largest share of thornyhead incidental catch from 2005 through 2011 (Murphy and Ianelli, 2011). The Sablefish fishery accounts for 60 - 75% of thornyhead discards; directed rockfish and flatfish fisheries account for the remaining discards (Murphy and Ianelli, 2011).

7.1.2.4 Biomass Estimates in the Bering Sea/Aleutian Islands

The U.S. and Japan conducted joint trawl surveys from 1979 through 1985 in the Bering Sea and from 1980 through 1986 in the Aleutian Islands to obtain biomass estimates for *Sebastes* and *Sebastolobus* species. Following the cessation of foreign commercial fishing in Alaskan waters, the U.S. continued to conduct trawl surveys without the aid of Japan. The U.S domestic trawl surveys were conducted in 1988, 1991, 2002, 2004, 2008, and 2010 in the eastern Bering Sea (EBS), and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, and 2012 in the Aleutian Islands

(AI) (Spencer and Rooper, 2010). The EBS slope survey covered depths from 200 m to 1200 m, whereas the AI survey only sampled depths to 500 m (Spies and Spencer, 2012). Consequently, biomass estimates of deep-water species such as thornyheads may have been underestimated in the AI survey. Shortspine Thornyhead estimates in the AI increased from 6153 t in 1991 to 18,075 t in 2010. Estimates of Shortspine Thornyhead biomass in the AI decreased to 14,443 t in 2012. The estimates (1991 through 2012) of Shortspine Thornyhead in the EBS have been more variable, ranging from 187 t to 1545 t (Spies and Spencer, 2012) (Figure 1).

7.1.2.5 Biomass Estimates in the Gulf of Alaska

Annual longline surveys were conducted jointly by the United States and Japan in the GOA from 1979 to 1994 to estimate the abundance of commercially important groundfish species in depths ranging from 101 m to 1000 m (Sasaki, 1985; Sigler and Fujioka, 1988). This depth range is divided into strata for sampling purposes. Thornyheads were assessed in depths ranging from 201 m to 1000 m. The catch rate, area, and size composition of samples taken from each depth stratum were used to ascertain the relative biomass for each depth stratum.

The longline surveys reported that thornyhead abundance increased when Sablefish abundance decreased. It was suggested that thornyhead catch rates increased between 1988 and 1989 because of an increase in availability of baited hooks with the decline in Sablefish. However, further research is needed on the level of hook competition between thornyheads and Sablefish (Murphy and Ianelli, 2011). Trawl surveys in the GOA have been conducted since the 1990s. Surveys conducted in the 1990s and 2001 did not extend depths greater than 500 m, where larger, older Shortspine Thornyheads concentrate. Surveys during 1999, 2005, 2007, and 2009 had the most extensive coverage of thornyhead depth and geographic range (Murphy and Ianelli, 2011). The 2011 estimated survey biomass of 63,180 t is a 20% decrease from the 2009 survey estimate. However, the 2011 biomass estimate did not include data from 701 m to 1000 m (Figure 2). Moreover, the decline of the 2011 biomass estimate compared to 2009 is only 9% when depths that exceeded 700 m were compared.

7.1.2.6 Changes in Stock Assessment Inputs and 2012-2013 ABC/OFL Recommendations

There were no changes in the assessment methodology for Shortspine Thornyheads in the BSAI or the GOA. For 2013 in the BSAI, the recommended maximum ABC for "other rockfish" is 1031 t. The maximum ABC for Shortspine Thornyheads in the BSAI is 664 t, and the OFL is 1375 t (Spies and Spencer, 2012). The maximum ABC and OFL for Shortspine Thornyhead in the GOA are 1665 t and 2220 t, respectively (Shotwell and Ianelli, 2012). The Shortspine Thornyhead stocks in both the BSAI and GOA were not subjected to overfishing last year (Shotwell and Ianelli, 2012; Spies and Spencer, 2012).

7.2 Pacific Ocean Perch

7.2.1 Life History

7.2.1.1 Morphology and Distribution

Pacific Ocean Perch (*Sebastes alutus*), the most abundant rockfish species in Alaskan waters, is of both ecological and economic importance (Love et al., 2002). Pacific Ocean Perch are a medium-sized pink rockfish with a greenish tinge on the side of their body (Love et al., 2002). Juveniles are darker in color and may be easily confused with juvenile Northern Rockfish. Pacific Ocean Perch range from the California coast to the Bering Sea (Gunderson, 1977).

One relatively successful method for studying the movement of Pacific Ocean Perch is the use of parasites as biological tags (Leaman and Kabata, 1987; Mosquera et al., 1999). Results of such studies suggest that Pacific Ocean Perch are influenced by onshore-offshore oceanographic currents and prey availability (Leaman and Kabata, 1987). Spatial studies of stock response to fishing pressure suggest limited dispersal of certain species of rockfish including Pacific Ocean Perch (Gunderson, 1997). Trawl surveys conducted between 1968 and 1992 off the northern Washington coast show that rockfish populations respond to fishing across small spatial scales (Gunderson, 1997). Further study could illuminate the mechanisms that influence Pacific Ocean Perch distribution and their resilience to fishing pressure at various geographic scales.

7.2.2.2 Trophic Interactions

Pacific Ocean Perch feed in the water column during the day and retreat to benthic habitat at night (Brodeur, 2000). Juveniles prey on a mix of calanoid copepods and euphausiids, whereas adult Pacific Ocean Perch feed primarily on euphausiids (Carlson and Haight, 1976; Yang and Nelson, 2000). Pacific Ocean Perch may compete with Walleye Pollock for euphausiid prey. It has been suggested that the large removal of Pacific Ocean Perch in Alaskan waters by foreign fleets during the 1960s led to Walleye Pollock population growth (Hanselman et al., 2005). Adult Pacific Ocean Perch also consume copepods, amphipods, myctophids, and snailfish (Yang, 1993; Brodeur, 2000). Predators of adult Pacific Ocean Perch include Sablefish, sperm whales, and Pacific Halibut, whereas predators of juvenile Pacific Ocean Perch are typically seabirds, other rockfish species, Lingcod (*Ophiodon elongatus*), and salmon (Major and Shippen, 1970; Ainley, 1993; Hobson et al., 2001). Little is known about population trends of Pacific Ocean Perch prey items and whether prey abundance affects population trends of Pacific Ocean Perch. The abundance of competitors for prey, such as Walleye Pollock, may also influence Pacific Ocean Perch populations (Hanselman et al., 2005).

7.2.2.3 Habitat

Adult aggregations of Pacific Ocean Perch are commonly found on shelf/slope or shelf/gully breaks along the continental shelf (Carlson and Haight, 1976; Gunderson, 1977; 1997). Shelf edge canyons have enhanced biomass from on-shore transport and concentration of zooplankton, both of which contribute to the high densities of the nekton in these canyons (Brodeur, 2000). Brodeur (2000) observed that adult Pacific Ocean Perch appear to prefer shelf habitat that has a high abundance of sea whips. Juvenile Pacific Ocean Perch are strongly associated with dense sponge and coral cover (Rooper and Boldt, 2005). In Southeast Alaska, Pacific Ocean Perch inhabit flat pebble substrate, whereas other rockfish prefer a hard substrate with high vertical relief (Logerwell et al., 2005).

Pacific Ocean Perch primarily occupy water temperatures ranging from 4.8 °C to 6.7 °C (Scott, 2007). Changes in ocean climate during El Nino/La Nina years have influenced rockfish abundance; populations typically decline during warm-water years (Miller and Sydeman, 2004). Numerous investigators have observed seasonal differences in depth distribution (Hanselman et al., 2011). In the summer, Pacific Ocean Perch occupy depths between 150 – 300 m, whereas in the fall they are thought to migrate to depths between 300 – 420 m (Love et al., 2002). Further research would provide a better understanding of the habitat preferences of Pacific Ocean Perch, their population distribution, location of critical habitats throughout the Pacific Ocean Perch life span, and the times of year when these habitats are necessary for survival.

7.2.2.4 Larval and Juvenile Stages

Relatively little is known about the life history of Pacific Ocean Perch, and much of the available data are from studies on Pacific Ocean Perch in Queen Charlotte Sound (Hanselman et al., 2005). Assumptions have been made that these life history data are extensible to Pacific Ocean Perch in other regions, such as in Alaskan waters. Pacific Ocean Perch are viviparous; females typically release their larvae during the spring (Gunderson, 1977; Moser and Boehlert, 1991). The exact location and depth of larval release is unknown in Pacific Ocean Perch; and without this knowledge, it is difficult to determine the influence of oceanic currents or geographic barriers on larval dispersal (Gunderson, 1977; Love et al., 2002). Since Pacific Ocean Perch undergo a pelagic larval stage for the first several weeks or even months of their life before settling into a demersal existence, oceanic currents may influence their dispersal (Carlson and Haight, 1976; Ainley et al., 1993; Kamin et al., 2014).

Survival rates may vary substantially among the offspring of different females, which may be a result of advection of some larvae to suboptimal areas (Ainley et al., 1993). Food availability may also be a limiting factor to the survival of Pacific Ocean Perch larvae. However, little is known about the feeding behavior of Pacific Ocean Perch in larval and post-larval stages (Hanselman et al., 2005).

Juvenile Pacific Ocean Perch between ages one and six are demersal. Older juveniles occur in the water column (Carlson and Haight, 1976). Juvenile Pacific Ocean Perch are associated with high-relief structured habitats such as rocky outcroppings, sponges, and corals (Rooper and Boldt, 2005; Rooper et al., 2007). Variation in the condition of juvenile Pacific Ocean Perch may depend on habitat type (Boldt and Rooper, 2009). Fish that occupy suboptimal areas were in poorer health than those in preferred habitats (Boldt and Rooper, 2009). Although prey availability and water temperature may be factors that contribute to a particular habitat's optimality, it is unclear which aspects affect the variation in juvenile Pacific Ocean Perch condition (Boldt and Rooper, 2009). By age six, Pacific Ocean Perch have moved offshore and to greater depths (Carlson and Haight, 1976). At age six, Pacific Ocean Perch are recruited to the fishery (Hanselman et al., 2011).

7.2.2.5 Reproduction

Female Pacific Ocean Perch produce between 10,000 and 300,000 eggs (Leaman, 1991). Older female rockfish, including Pacific Ocean Perch, may produce more eggs and their larvae may have higher survival rates than those of younger, smaller females (Berkeley et al., 2004; Bobko and Berkeley, 2004). Mating takes place offshore in the fall, after which the ova undergo delayed fertilization. Females migrate to water between 500 m and 700 m in the winter, while males remain in shallower waters (200 – 400 m) where males and females co-occur during the summer months (Gunderson, 1977; Love et al., 2002). Parturition occurs in April and May, coinciding with large plankton blooms in the GOA, which provides an important food source for Pacific Ocean Perch (Gunderson, 1977; Yang, 1993).

7.2.2.6 Age Structure

Pacific Ocean Perch is a slow growing species with a low estimated natural mortality rate of 0.06 (Hanselman et al., 2003). Age and growth studies have indicated that Pacific Ocean Perch reach 50% maturity between 6 and 10 years of age and live an average of 30 years, with a maximum lifespan of 98 years (84 years in the GOA) (Alverson and Westrheim, 1961; Paraketsov, 1963; Hanselman et al., 2003; Rooper and Boldt, 2005). Size at maturity for Pacific Ocean Perch varies latitudinally between the western GOA, the southeastern GOA, and southeastern Vancouver Island (Lunsford, 1999).

The break-and-burn aging method was used to determine age at maturity for Pacific Ocean Perch in the eastern GOA. Results indicated that Pacific Ocean Perch typically do not reach 50% maturity until they are approximately 10.5 years old (Lunsford, 1999). As with many species, which exhibit a relatively late onset of maturity and have increased fecundity with age, there is a risk that populations will be fished out before sufficient time has elapsed to replenish stocks. There is also concern that selectively fishing for larger, faster-growing Pacific Ocean Perch could increase population declines of Pacific Ocean Perch if larger, older fish are more reproductively viable.

7.2.2.7 Population Structure

Along with frequent biomass estimates, an understanding of the population structure of various rockfish is required to maintain a sustainable management regime (Hanselman et al., 2005). Previous studies of marine species have detected little or no population structure (Palumbi, 1994; Garoia et al., 2004). Demographic characteristics such as large population size or pelagic larvae and mobile adults may account for the apparent weak population structure in some marine organisms (Palumbi, 1994). However, the population structure of some species may not have been accurately detected because of limited genetic technologies that had low resolution (Olsen et al., 2002; Palof, 2008).

Until recently, the general consensus within the scientific community was that marine species have high dispersal capabilities, resulting in species consisting of a genetically homogenous or panmictic population across their range (Conover et al., 2006). However, recent research has shown that a variety of marine species exhibit geographic population structure and are capable of undergoing localized adaptation within a contemporary time scale (Conover et al., 2006). Thus, a thorough knowledge of a species' population substructure is an essential component of fish conservation genetics. Genetic diversity may be lost if one subpopulation which contains unique genetic material is depleted (Conover et al., 2006). Also, if one stock is overharvested, it may not be rapidly replenished by migrants. Replenishment depends on the level of dispersal, which can be measured in part by the genetic differentiation of neutral markers among subpopulations (Conover et al., 2006). One problem with determining the level of dispersal among populations is the effect of natural selection on a population. For instance, even if subpopulations are connected by a high level of gene flow, they may exhibit genetic differentiation if there is strong natural selection (Schneider et al., 1999).

Population substructure may be difficult to detect in continuously distributed species unless examined at the appropriate geographic scale. In widely and continuously distributed species, genetic divergence can occur if an individual's movement throughout their lifetime is much less than the species range. Genetic exchange will only occur among individuals in relatively close proximity to each other, thus creating genetic structure within the population. As a result, genetic divergence would be expected to increase with geographic distance (Matala et al., 2004). However, in large marine populations, restricted dispersal may not result in substantial genetic divergence as measured by F_{st} values (F_{st} is an index of genetic divergence among populations) (Weir and Cockerham, 1984). In addition, the type of genetic analysis used to determine genetic divergence may produce different results. For instance, during a study on the population structure of Brown Trout (*Salmo trutta*) in Norway that used amplified fragment length polymorphisms (AFLPs) and microsatellites, microsatellites indicated a greater genetic diversity among populations (Sonstebo et al., 2007).

Genetic and biochemical markers have been used to characterize many aspects of rockfish life history and dispersal patterns. Mitochondrial DNA has been used to distinguish different species (Gharrett et al., 2001) and to define variation within a species of rockfish, such as the Rosethorn Rockfish (*S. helvomaculatus*; Rocha-Olivares and Vetter, 1999). The use of mitochondrial DNA to define sub-populations within a species has also been successful; two sub-populations have been characterized for the Blue Rockfish (*S. mystinus*) off the western coast from Washington to California (Cope, 2004). However, for some species mitochondrial DNA does not have sufficient variation to differentiate populations, (Buonaccorsi et al., 2005). Consequently, microsatellite markers are often used to determine genetic sub-structure because they allow for fine-scale resolution that other markers may not obtain (Roques et al., 1999; Withler et al., 2001; Roques et al., 2002; Matala et al., 2004).

Demersal fish, such as some rockfish species, disperse primarily during their planktonic larval stage, rather than as adults (Buonaccorsi et al., 2005). Thus, it is possible that the distribution of rockfish subpopulations and the replenishment of locally depleted areas are because the movement of pelagic larvae rather than settled adults (Buonaccorsi et al., 2005). Traditionally, scientists have thought that widely dispersing fish larvae lead to panmictic fish populations. Based on allozyme variation it was concluded that Pacific Ocean Perch were genetically similar throughout their range and that genetic exchange may be the result of dispersal during their larval stage (Seeb and Gunderson, 1988).

The advance of genetic analysis methods has contributed to a better understanding of population substructure in fish populations, including Alaska rockfish such as Pacific Ocean Perch. Observations of distinct biological characteristics between Pacific Ocean Perch inhabiting shallow versus deep water in Queen Charlotte Sound suggested the presence of two stocks of Pacific Ocean Perch in Canada (Westrheim, 1975). This apparent population substructure has been supported by microsatellite analysis. Withler et al. (2001) observed distinct genetic populations of Pacific Ocean Perch on a small scale in British Columbia. In spite of the many opportunities for most life stages to disperse there was strong geographically related genetic structure (F_{st} = 0.0123, $P < 10^{-5}$). In addition, there was evidence of isolation by distance, suggesting that limitations in Pacific Ocean Perch dispersal influenced the level of genetic exchange among populations (Withler et al., 2001; Palof et al., 2010).

Adult Pacific Ocean Perch appear to belong to neighborhoods that exchange genetic information at relatively small spatial scales (14 to 90 km) (Palof et al., 2010). Although this suggests limited movement, connectivity is evidenced by the isolation-by-distance relationship, by the apparent northwestward movement of gene flow in the GOA, and by the break in gene flow in the central GOA (Palof et al., 2010). The observed population structure has a finer geographic scale than established management areas, which suggests that current fisheries management should be revisited (Palof, 2008). Efforts should be made to understand the mechanisms that influence Pacific Ocean Perch dispersal and, consequently, affecting their population structure. Failure to do so could result in the overexploitation of subpopulations containing unique genetic material and eventually lead to a loss of adaptive potential in the species overall.

7.2.2 Management

7.2.2.1 Historical and Current Fisheries

Commercial fishing of Pacific Ocean Perch began in 1946 by U.S. trawlers off the central Oregon coast (Alverson and Westrheim, 1961). The fishery gradually expanded as far north as Queen Charlotte Sound, B.C. In 1960, foreign fleets primarily from Japan and the Soviet Union began fishing for Pacific Ocean Perch in the Bering Sea and expanded into the GOA in 1963 (Ito, 1986). The total harvest in the GOA peaked in 1965 at 350,000 t, but began a steady decline in the late 1960s and 1970s, falling to only 8000 t in 1978 (Hanselman et al., 2005). It is believed that the reduction in Pacific Ocean Perch abundance was because of overexploitation by foreign fishing vessels (Hanselman et al., 2005). Consequently, between 1967 and 1984 Pacific Ocean Perch stocks off Alaska were reduced by 80% from virgin biomass estimates (Gunderson, 1977; Ito, 1986; Hanselman et al., 2005).

Foreign fleets continued to dominate the Pacific Ocean Perch fishery in the GOA until 1985, when the annual catch reached a minimum (Hanselman et al., 2005). In 1985 foreign fishing of Pacific Ocean Perch in the GOA was prohibited and domestic trawl fishing of Pacific Ocean Perch increased because of higher annual quotas (Hanselman et al., 2005). However, in 1991 increased restrictions were placed on the total allowable catch (TAC) until 1996, when good recruitment and high levels of Pacific Ocean Perch biomass permitted higher TACs (Hanselman et al., 2005). Since Pacific Ocean Perch are exploited throughout most of their range and are still recovering from overharvesting in previous decades, careful management is critical for maintaining sustainable populations. The vulnerability of Pacific Ocean Perch to overfishing may stem from their relatively late age at maturity.

Bottom trawls accounted for the majority of commercial harvest of Pacific Ocean Perch by domestic fleets in the 1990s (Hanselman et al., 2005). In the late 1990s/early 2000s, pelagic trawls harvested an increased proportion of Pacific Ocean Perch catch in the GOA (Hanselman et al., 2005). In the GOA, the percentage of Pacific Ocean Perch caught in pelagic trawls increased from between 2 - 8% during 1990 - 1995 to between 14 - 20% during 1996 - 1998 and has remained within this range in recent years (Hanselman et al., 2005).

7.2.2.2 Biomass Estimates in the Gulf of Alaska

Although Pacific Ocean Perch show signs that their population is no longer in decline from commercial fishing, life history characteristics and past fishing records suggest that they are susceptible to overharvesting (Palof et al., 2010). Following the precipitous decline in Pacific Ocean Perch biomass during the 1960s and 1970s, triennial trawl surveys have been conducted since 1984 in the GOA to estimate Pacific Ocean Perch abundance in order to prevent future overharvesting (Lunsford et al., 2001). However, it is difficult to determine sustainable harvest rates year to year because Pacific Ocean Perch undergo high inter-annual variability in recruitment caused by variations in oceanographic conditions (Leaman and Beamish, 1984; Botsford et al., 1994; Ralston and Howard, 1995). In addition, because there may be geographic differences in the timing of larval release, an entire year class may not experience the same environmental conditions (Berkeley and Markle, 1999).

Current management policy assigns Pacific Ocean Perch in the GOA an ABC and a TAC, which is determined annually based on the ABC. The ABC and TAC for Pacific Ocean Perch are divided among three geographical management zones in the GOA (Western, Central, and

Eastern) based on the distribution of Pacific Ocean Perch biomass (Hanselman et al., 2005). However, genetic analysis has detected further substructure suggesting a need to revise management areas according to genetic population structure rather than according to broad geographic regions (Palof et al., 2010).

7.2.2.3 Biomass Estimates in the Bering Sea/Aleutian Islands

Since 2001, Pacific Ocean Perch in the BSAI have been managed as a single stock because of lack of data on Pacific Ocean Perch population structure (Spencer and Ianelli, 2010). However, in recent years separate ABCs have been assigned to four geographically distinct areas within the BSAI. These four management areas include: western AI, central AI, eastern AI, and EBS (Spencer and Ianelli, 2011). In 2005 BSAI rockfish, including Pacific Ocean Perch, were placed under biennial assessments to coincide with biennial trawl surveys of the AI and the EBS slopes (Spencer and Ianelli, 2011).

7.2.2.4 Incidental Catch

Pacific Ocean Perch is caught in other groundfish fisheries as bycatch, though levels of discards of Pacific Ocean Perch have generally declined since 2005 (See Table 4). In the GOA, non-rockfish fisheries that catch substantial quantities of Pacific Ocean Perch include the Rex Sole (*Glyptocephalus zachirus)* and Arrowtooth Flounder, average 500 t per year. Pacific Ocean Perch is also taken in other flatfish, Pacific Cod, and Sablefish fisheries (Hanselman et al., 2009).

7.2.2.5 Changes in Stock Assessment Inputs and 2012 ABC/OFL Recommendations

Catch data in the BSAI from 2010 led to revisions for the recommended ABC for 2012. The 2010 catch was 17,851 t, which was 5.3% lower than the projected 2010 estimate of 18,860 t. The total estimated 2011 catch was 20,604 t (summing 17,872 t caught through Sept. 2011 and average catch of 2732 t from Oct. - Dec. 2001-2010) (Spencer and Ianelli, 2011). The 2011 ABC was set to 24,700 t, which resulted in a lower exploitation rate than is typically used for tier 3 fisheries, as a precautionary measure in response to a large increase in estimated biomass in the 2010 stock assessment. This value was also used as the estimated catch for 2012 and 2013 (Table 5-6).

Catch data in the GOA led to revisions to the ABC for 2012. Changes in input data for 2012 included: 2011 survey biomass estimates, 2009 survey age compositions, 2010 fishery age compositions, a revised catch estimate for 2010 and a new catch estimate for 2011. For the 2012 Pacific Ocean Perch fishery in the BSAI, the recommended maximum allowable ABC was 16,918 t according to the updated model. The stock is not overfished, nor is it approaching overfishing status (Hanselman et al., 2011). Although more is known about Pacific Ocean Perch biology than about many other rockfish species, there are still gaps in data regarding Pacific Ocean Perch reproductive biology, distribution, habitat requirements, and population structure (Spencer and Ianelli, 2011). In the 2012 stock assessment, data collected during 2010 on proportion mature by age were included (Spencer and Ianelli, 2011).

7.3 Shortraker Rockfish

7.3.1 Life History

7.3.1.1 Morphology and Distribution

The Shortraker Rockfish (*Sebastes borealis*) is an offshore, demersal species that occupies waters from the Kamchatka Peninsula to Fort Bragg, California (Krieger, 1992). They appear to be most abundant in Alaskan waters (Clausen and Echave, 2011). The Shortraker Rockfish gained its name from its relatively short, stubby gillrakers. They have several other common names, including buoy keg, snapper, and black-throated rockfish (Love et al., 2002). Shortraker Rockfish are primarily pink, with large dark pink, pink-orange, or red blotches spread over their body. Shortraker Rockfish are the largest of all *Sebastes*, and can reach a maximum length of 120 cm and maximum weight of 23 kg (Krieger, 1992; Love et al., 2002; Mecklenberg et al., 2002; Clausen, 2009). Shortraker Rockfish are larger in deep water off the AI than their conspecifics in shallow Southeast Alaska waters (Hawkins et al., 2005). The observed difference in size with depth may reflect different cohorts occupying varied depths/locations given that older, larger Shortraker Rockfish often occupy deeper water than younger, smaller ones (AFSC, 2011). However, difference in size at depth between these locations could be a function of spatial variation in growth rates at a given age. Studies on other rockfish in the GOA have demonstrated that growth can vary with both latitude and longitude (Malecha et al., 2007).

7.3.1.2 Trophic Interactions

Shortraker Rockfish are generalist feeders; they prey on a variety of marine organisms including myctophids, bathylagids, mysids, and shrimp (Yang et al., 2006). Shrimp comprise the majority of their diet, followed by myctophids and squid (Yang et al., 2006). Unfortunately, little is known about abundance trends of these prey items or whether fluctuations in abundance strongly contribute to year-class strength of Shortraker Rockfish (Yang and Nelson, 2000; Yang, 2003; Yang et al., 2006; Clausen and Echave, 2011). Changes in water temperature and localized currents may influence the abundance of prey items. Larval and juvenile Shortraker Rockfish are prey for a variety of fish and marine mammals. The level of predation on larval and juvenile Shortraker Rockfish could also substantially affect year-class strength. It is believed that sleeper sharks and sperm whales may prey on older, larger Shortraker Rockfish, but otherwise larger adults have few predators (Clausen and Echave, 2011).

7.3.1.3 Age

Shortraker Rockfish, one of the longest-lived rockfish, live up to 157 years (Munk, 2001; Love et al., 2002). As a long-lived species, the Shortraker Rockfish is relatively slow growing and slow to reach maturity. According to McDermott (1994) Shortraker Rockfish reach 50% maturity at approximately 20 years. It is difficult to age Shortraker Rockfish with otoliths though Hutchinson (2004) developed a method that uses some sections of the otolith and uses innovative aging criteria to determine which growth bands correspond to an annulus. The use of otoliths has provided limited age validation of Shortraker Rockfish collected during trawl surveys in the GOA in recent years (Clausen and Echave, 2011). Currently efforts are underway to validate aged otoliths with radiometric aging (AFSC, 2011). The ratio of lead (^{210}Pb) to radium (^{226}Ra) in the core of an otolith can be measured to estimate the age of that otolith (AFSC, 2011). Data collected from GOA trawl surveys in 1996, 2003, and 2005 indicated that Shortraker Rockfish ranged from 5 - 146 years in this region, and the mean age for each survey ranged between 32 and 44 years (Clausen and Echave, 2011).

7.3.1.4 Reproduction

Depending on geographic location, Shortraker Rockfish may mature at slightly different ages because of differences in growth rate. For instance, fish that mature at a larger size (e.g., off the Oregon coast) may be maturing at a later age than fish which mature at a smaller size, such as those off the GOA (Love et al., 2002). Nonetheless, their old age at maturity relative to other rockfish species may put them at a greater risk of overfishing than species that mature more quickly and have greater opportunity to reproduce before capture.

Shortraker Rockfish are viviparous (Clausen, 2009). Parturition takes place between February and August (McDermott, 1994). Studies suggest that parturition occurs at depths of 300 - 500 m in the Bering Sea and off the coast of Kamchatka (Love et al., 2002). However, there are few data on whether Shortraker Rockfish migrate for breeding (Love et al., 2002). The fecundity of Shortraker Rockfish is unknown, though it has been demonstrated that larger rockfish have substantially higher fecundities than smaller species (Love et al., 2002; Clausen and Echave, 2011). Since the Shortraker Rockfish is one of the largest North Pacific rockfish, its fecundity likely falls in the higher end of rockfish's range for egg production. Fecundity among 33 northeast Pacific rockfish species ranges from approximately 18,000 eggs in the Dwarf Calico Rockfish (*Sebastes dallii*) to 2,700,000 in the Yelloweye Rockfish (Love et al., 2002). However, since Shortraker Rockfish can be larger than Yelloweye Rockfish, they may have an even higher average fecundity (Love et al., 2002).

7.3.1.5 Larval and Juvenile Stages

Shortraker Rockfish larvae are pelagic, but it is unknown when juveniles in the GOA assume a demersal existence (Clausen, 2009). It is difficult to assess the abundance and distribution of rockfish larvae, since numerous rockfish species have morphologically similar larvae (Spencer and Reuter, 2008). However, Shortraker Rockfish larvae have been distinguished from other rockfish larvae by using genetic techniques (Clausen and Echave, 2011). Shortraker Rockfish larvae have been found near Kodiak Island, the Semidi Islands, Chirikof Island, the Shumagin Islands, and near the eastern end of the AI (Spencer and Reuter, 2008). They tend to associate with kelp patches, which are influenced by ocean currents (Clausen and Echave, 2011). It has been suggested that Shortraker Rockfish larvae are transported via currents in the GOA to nursery grounds in the Aleutians, where they mature before migrating back to the GOA as adults (Orlov, 2001). This idea is supported by data from biennial GOA trawl surveys, which indicate that adult Shortraker Rockfish are fairly abundant near Chirikof Island. However, further research is needed on the Shortraker Rockfish larval and juvenile stages. Very few juvenile Shortraker Rockfish (< 35cm fork length) have been collected in this region, so little is known about this life stage (Clausen and Echave, 2011). Juvenile Shortraker Rockfish off of Kamchatka may become demersal once they reach a fork length of about 10 cm (Orlov, 2001).

7.3.1.6 Habitat Preferences

Shortraker Rockfish were historically classified as the same species as Rougheye Rockfish because their similar morphologies and habitat preferences (Jordan and Evermann, 1898). Barsukov (1970) described Shortraker Rockfish as a distinct species from Rougheye Rockfish. Tsuyuki and Westrheim (1970) confirmed the distinction between Shortraker Rockfish and Rougheye Rockfish by using biochemical methods. Shortraker Rockfish are most common at depths between 300 m and 600 m and are often found along the upper continental slope (Krieger, 1992; Clausen, 2009). However, they have a wide depth range from 25 - 1200 m (AFSC, 2011). Older Shortraker Rockfish tend to inhabit deeper waters than younger ones (AFSC, 2011).

Shortraker Rockfish are not entirely benthic; they frequently hover 10 m above the substrate (AFSC, 2011).

According to observations from a submersible, Shortraker Rockfish inhabit a range of slopes, from steep slopes with numerous boulders, to gradual slopes with few boulders. However, they are most abundant on steep slopes with a high density of boulders (Krieger, 1992; Krieger and Ito, 1999). Juvenile Shortraker Rockfish have been reported to associate with both abiotic and biotic structures (Carlson and Straty, 1981; Pearcy et al., 1989; Love et al., 1991). Adult Shortraker Rockfish use *Primnoa* spp. corals for shelter (Krieger and Wing, 2002). Shortraker Rockfish have a relatively even distribution as compared to other rockfish, such as Pacific Ocean Perch, which are found in patchy aggregations (Clausen and Fujioka, 2007). Our knowledge of Shortraker Rockfish habitat preferences is limited by the difficulty in conducting trawl surveys in their habitat, which is relatively steep and boulder strewn (Krieger, 1992). Further research of Shortraker Rockfish habitat preference is needed, given that their survival rates may be affected by natural or anthropogenic changes in habitat. Changes in their environment could influence the ability of Shortraker Rockfish to find shelter from predators and to catch prey in addition to affecting them physiologically.

7.3.1.7 Biomass Estimates in the Bering Sea/Aleutian Islands

The U.S. and Japan conducted joint trawl surveys from 1979 through 1985 in the Bering Sea and from 1980 through 1986 in the AI to obtain biomass estimates for red rockfish, including Shortraker Rockfish. Following the cessation of foreign commercial fishing in Alaskan waters, the U.S. conducted trawl surveys without the participation of Japan. The U.S domestic trawl surveys were conducted in 1988, 1991, 2002, 2004, 2008, and 2010 in the EBS, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, and 2010 in the AI (Spencer and Rooper, 2010). The biomass estimates from the AI survey are used as a suitable index of the BSAI Shortraker Rockfish because the majority of the population is thought to be located in the AI. Because the methods used in the cooperative biomass estimates made by the U.S. and Japan prior to 2003 differed from recent methods conducted by the U.S. alone, the earlier estimates have not been incorporated into recent estimates (Spencer and Rooper, 2010).

The biennial EBS slope survey was initiated in 2002 and may help to provide more accurate biomass estimates of Shortraker Rockfish in the BSAI when coupled with AI survey data. The most recent EBS survey prior to 2002, excluding preliminary tows in 2000 intended to evaluate survey gear, was in 1991. The estimates of Shortraker Rockfish biomass Shortraker Rockfish from the 2002 - 2010 EBS surveys have ranged between 2570 t in 2004 and 7308 t in 2008 (Spencer and Rooper, 2010). The estimated biomass of Shortraker Rockfish decreased from 28,850 t in 1980 to 25,269 t in 1997, and steadily declined to 17,452 t in 2009 (Figure 1). The EBS survey results have not been used in stock assessments as of 2010, and the feasibility of incorporating this time series will be evaluated in future years (Spencer and Rooper, 2010).

7.3.1.8 Biomass Estimates in the Gulf of Alaska

Bottom trawl surveys were conducted in the GOA triennially from 1984 through 1999 and became biennial surveys starting in 2001 (Clausen and Echave, 2011). These surveys have provided substantial data on Shortraker Rockfish biology, including abundance trends and size composition. Data from the surveys have shown that Shortraker Rockfish biomass in the GOA has fluctuated somewhat during the last three decades, though for most years the differences in biomass do not appear to be significant. There was a large drop in estimated biomass from 42,851 t in 1987 to 12,681 t in 1990, though it has been steadily increasing since then and reached a biomass estimate of 44,185 t in 2009 (Clausen and Echave, 2011). Because a 25%

decrease in estimated biomass over one year is biologically unlikely, steep declines in estimated biomass probably reflect sampling error. The year 2011 saw the highest Shortraker Rockfish biomass estimate to date at 64,835 t and an unusually high survey catch (Figure 1). Much of the increase in survey catch during 2011 resulted from an unusually large catch (1.6 t in a single haul) in the Chirikof area (Clausen and Echave, 2011). Thus, these estimates may not be fully indicative of Shortraker Rockfish abundance trends.

Adult Shortraker Rockfish appear to prefer depths of 300 – 500 m along the continental slope and the typically rocky substrate in these areas is difficult to trawl (Clausen and Echave, 2011). Longline surveys, which can be conducted over rocky substrate, may provide better information on shortraker abundance, distribution, and biomass trends. Longline surveys have indicated that Shortraker Rockfish are particularly abundant near Yakutat, although trawl surveys did not detect an abundance of Shortraker Rockfish there (Clausen and Echave, 2011).

7.3.1.9 Population Structure

Matala et al. (2004) observed evidence of genetic population structure in Shortraker Rockfish from southern Baranof Island to the western Aleutian Islands. According to genetic analyses, the population structure of Shortraker Rockfish is at a relatively large geographic scale, consistent with the three management zones in Alaskan waters: GOA, AI, and the EBS. Three genetically distinct groups were identified: a Southeast Alaska group, a group ranging from Southeast Alaska to Kodiak Island, and a group ranging from Kodiak Island to the central AI (Matala et al., 2004; Spencer and Reuter, 2008). Shortraker Rockfish size differences varied from east to west (Matala et al., 2004). These size differences may be indicative of genetic variability and are correlated to divergent oceanographic and biological influences acting on populations with limited migration or movement. However, if there were substantial movement and homing to natal grounds, the size differences could be related to the ages of cohorts that have a segregated distribution along the Pacific Rim. Alternatively, if there is not significant variation in age class moving from east to west, there may be different average sizes at a given age depending on location. Another possibility is that historical fishing pressures selectively removed Shortraker Rockfish, altering the size and age distribution. Population genetic analyses suggest that individual Shortraker Rockfish have a fairly small home range in comparison to their overall species range, providing a potential opportunity for genetic divergence among demes (Matala et al., 2004; Clausen, 2009).

The apparent population structure of Shortraker Rockfish in Alaskan waters may be attributable to several factors. If larval dispersal and adult movement are restricted, then the structure may reflect geographic segregation. Oceanographic features such as eddies and onshore currents may retain larvae and prevent their dispersal or disperse them at different times (Owen, 1980; Wing et al., 1998). Large geographic barriers to dispersal, such as the Dixon Entrance, may create population substructure (Williams and Ralston, 2002; Cope, 2004; Matala et al., 2004). Behavior of juveniles during settlement could further promote local retention since many rockfish become relatively stationary once they reach adulthood (Larson et al., 1994; Drake et al., 2010).

It has been suggested that Shortraker Rockfish adults return to natal areas to spawn after dispersing during their larval stages (Orlov, 2001). Relatively few spawners in a given year may contribute to a particular cohort, potentially leading to population substructure (Spencer and Reuter, 2008). If this is the case, the population structure may be due in part to genetic differences among individuals in different cohorts, rather than due solely to geographic separation. Further data on Shortraker Rockfish size, age composition, and age at maturity are needed to better understand the level of complexity of Shortraker Rockfish cohort structure (Matala et al., 2004).

In order to more fully understand Shortraker Rockfish population structure, there should also be further study of Shortraker Rockfish life history characteristics, particularly age composition, age at maturity, and size at age. Unfortunately interpretation of annuli on Shortraker Rockfish otoliths is very difficult (Clausen, 2009). If adequate sample sizes could be collected from geographically distinct sites, then life history characteristics such as larval distribution, genetic diversity and structure, and reproductive strategies may be useful to determine the stock structure of rockfish such as the Shortraker Rockfish. Shortraker Rockfish biological data, such as identification of their larvae, average and maximum fecundities, and breeding habits, may assist in promoting effective management and conservation strategies. It is imperative that further studies of Shortraker Rockfish and other long-lived rockfish are undertaken in order to minimize the risk of eventually overfishing their populations.

7.3.2 Management

7.3.2.1 Management in the Bering Sea Aleutian Islands

The management of Shortraker Rockfish in the EBS and AI management areas began in 1979 (Spencer and Reuter, 2008). Shortraker Rockfish were managed in the EBS and AI within the Pacific Ocean Perch regulatory complex between 1979 and 1990. During that time, the Pacific Ocean Perch complex included four species other than Shortraker Rockfish: Pacific Ocean Perch, Northern Rockfish, Rougheye Rockfish (which was recognized as two species in 2005), and Sharpchin Rockfish (Gharrett et al., 2005; Spencer and Reuter, 2008).

In 1991, the NPFMC removed Pacific Ocean Perch from the Pacific Ocean Perch complex to be managed as a separate species (Spencer and Reuter, 2008). In the EBS, the Pacific Ocean

Perch complex was divided into two subgroups: (1) Pacific Ocean Perch, and (2) other red rockfish, which included Shortraker Rockfish, Northern Rockfish, Rougheye Rockfish, and Sharpchin Rockfish. In 2001 the EBS red rockfish group was further subdivided into Rougheye Rockfish/Shortraker Rockfish and Sharpchin Rockfish/Northern Rockfish sub-complexes. In the AI management area the Pacific Ocean Perch complex was divided into three subgroups: (1) Pacific Ocean Perch, (2) Shortraker Rockfish/Rougheye Rockfish, and (3) Northern Rockfish/Sharpchin Rockfish. These sub-complexes were developed to prevent overfishing of Pacific Ocean Perch, Shortraker Rockfish, and Rougheye Rockfish, three commercially valuable species (Spencer and Reuter, 2008).

In 2002, Sharpchin Rockfish were removed from the red rockfish EBS and AI regulatory complexes and placed in the "other slope rockfish" management category. From 1991 through 2004, Shortraker Rockfish and Rougheye Rockfish were assigned a single overall ABC and TAC, and fishermen could freely harvest either species within those limits (Clausen and Echave, 2011). However, in 2004 data from the NMFS Alaska Observer Program suggested that Shortraker Rockfish was being disproportionately harvested within the Shortraker Rockfish/Rougheye Rockfish complex, which could lead to future overharvesting of Shortraker Rockfish (Clausen, 2004). In order to address this concern the NPFMC placed Shortraker Rockfish and Rougheye Rockfish into individual management categories starting in 2005 (Clausen and Echave, 2011).

7.3.2.2 Management in the Gulf of Alaska

In 1988 in the federal waters in the GOA, rockfish were divided into three groups based on their general habitat preferences as adults (Clausen et al., 2011). Shortraker Rockfish were originally assessed as part of the "slope rockfish" complex, along with 15 other rockfish species

(Clausen and Echave, 2011). In 1991, Shortraker Rockfish and Rougheye Rockfish were removed from the slope rockfish regulatory complex to be managed separately (Clausen and Echave, 2011). Since the 1990s, directed fishing of Shortraker Rockfish has not been permitted; they may only be caught as incidental catch (Clausen and Echave, 2011). Since 1998, annual catch has averaged 600–900 t and have been much lower than the ABC or TAC (Clausen and Echave, 2011). In 2005, Shortraker Rockfish and Rougheye Rockfish began to be managed individually (Clausen and Echave, 2011; Clausen et al., 2011). The “other slope rockfish” group was renamed “other rockfish” following the addition of Widow Rockfish and Yellowtail Rockfish, which both inhabit the continental shelf (Clausen and Echave, 2011).

7.3.2.3 Catch Trends

Catches of Shortraker Rockfish were relatively high in the 1970s, and declined in the late 1980s as the foreign fishery was vastly reduced. Foreign fisheries did not report Shortraker Rockfish as one species but within management categories such as “other species” (1977 and 1978), “Pacific Ocean Perch complex” (1979 – 1985, 1989), and “rockfish without Pacific Ocean Perch” (1986 – 1988) (Spencer and Reuter, 2008). Although the foreign fishery declined, the domestic fishery increased and subsequently catches of Shortraker Rockfish increased in the early 1990s but dropped again in the mid-late 1990s (Spencer and Reuter, 2008). Because of the high economic value of Shortraker Rockfish, their discard rate has historically been lower than that for less valued red rockfish (Spencer and Reuter, 2008). Shortraker Rockfish in the AI have primarily been caught in longline fisheries for Turbot, Arrowtooth Flounder, Sablefish, Pacific Halibut, and the Pacific Cod and rockfish trawl fisheries (Spencer and Reuter, 2008). From 2004 through 2007, these fisheries accounted for approximately 90% of Shortraker Rockfish catches in the AI, the majority of which occurred in the central AI. Pollock and mid-water trawl fisheries for Arrowtooth Flounder and longline fisheries for Pacific Cod, Turbot, and Pacific Halibut accounted for 92% of the Shortraker Rockfish catch in the eastern Bering Sea (Spencer and Reuter, 2008). In general, Shortraker Rockfish catches in the AI have not exceeded their ABC. However, in the EBS catches of Shortraker Rockfish surpassed its ABC levels from 2002 through 2005, and during 2007 (Spencer and Reuter, 2008). If the annual catch continues to exceed the ABC, there is a risk that Shortraker Rockfish may become overfished.

Shortraker Rockfish are managed solely as incidental catch (Love et al., 2002). Shortraker Rockfish are managed under tier 5 of the NPFMC BSAI Groundfish FMP. The value for Shortraker Rockfish F_{ABC} is defined as 75% of the natural mortality rate (M) of Shortraker Rockfish (Spencer and Rooper, 2010). In 2009 and 2010, the estimated stock biomass in the BSAI for Shortraker Rockfish was 17,187 t. The estimate for 2011 through 2012 was 17,412 t (Spencer and Rooper, 2010). The natural mortality for Shortraker Rockfish is assumed to be $M = 0.03$. When the shortraker/rougheye management complex was created in 1991, there was no estimate of M for Shortraker Rockfish, so a proxy was determined by using the ratio of maximum age of Rougheye Rockfish to Shortraker Rockfish (140 years/120 years) from British Columbia and multiplying this ratio by the mid-point of the range of Z for Rougheye Rockfish in British Columbia. This calculation yielded a value of $M = 0.03$. In a 1994 study, M for Shortraker Rockfish was estimated between 0.027 and 0.042. Since 0.03 fell within this range, NMFS continues to use this value for M (McDermott, 1994; Clausen and Echave, 2011). Knowledge of a species' natural mortality allows the ABC to be estimated more accurately. Using the value $M = 0.03$, the ABC for 2009 was determined to be 387 t.

Recent data on the age-structure of Shortraker Rockfish and maturity has become available for the GOA, which would qualify Shortraker Rockfish to be managed under tier 4. However, since there is still a great deal of uncertainty regarding current Shortraker Rockfish age validation methods, it has been recommended that Shortraker Rockfish remain in tier 5 in the GOA (Clausen and Echave, 2011). There is a lack of age-structure data on Shortraker Rockfish in the BSAI, so BSAI Shortraker Rockfish are managed under tier 5 (Spencer and Ianelli, 2011). Using the standard estimate for tier 5 species of $M = 0.03$ and the current exploitable biomass estimate, the recommended ABC for the GOA is 1081 t for 2012 (Clausen and Echave, 2011). The total ABC is apportioned geographically according to relative estimated biomass in each of the three areas: West, Central, and East. 9.59%, 41.82%, and 48.59% of the total ABC are allotted for 2012 to each area, respectively (Clausen and Echave, 2011). Using the recommended ABC value of 1081 t for the GOA in 2012, the Western area is allotted an ABC of 104 t, the Central area is allotted an ABC of 452 t, and the Eastern area is allotted an ABC for 525 t.

Based on the estimated $M = 0.03$ and the current estimated exploitable biomass of 48,048 t, the overfishing catch limit for 2012 is 1441 t, an increase from 1219 t in 2011 (Table 8). The increase in catch limit for 2012 may be because of an especially high catch during a trawl survey in 2011. During 2011 a 25% increase in annual Shortraker Rockfish survey catch was observed, which may be attributable to unusually high survey catches in the Chirikof Islands that year. Currently ABCs for Shortraker Rockfish are calculated from survey biomass estimates, though once aging methodology has been further validated, an age-structured assessment may be used for Shortraker Rockfish (Clausen and Echave, 2011).

Although Shortraker Rockfish are not currently considered overfished, relatively little is known about the biology of this long-lived species, which puts it at greater risk of overfishing than shorter-lived, faster-growing species. It has been proposed that the implementation of marine reserves in the GOA may provide an effective conservation strategy for shortraker and other rockfish in the future (Soh et al., 2001). Population dynamics models have projected that over 20 years there would be fewer Shortraker Rockfish discards and a reduced risk of overfishing, while maintaining current catch levels (Soh et al., 2001). However, the effectiveness of the proposed reserves would be contingent upon whether they are placed in areas thought to have a consistently high concentration of Shortraker Rockfish and whether these areas were previously heavily fished.

7.3.2.4 Incidental Catch

Most of the incidental catch of Shortraker Rockfish occurred in trawl fisheries (Ackley and Heifetz, 2001). Shortraker Rockfish are typically taken by fisheries targeting other rockfish, Sablefish, Pacific Halibut, and Walleye Pollock (Ackley and Heifetz, 2001).

There are anecdotal reports of topping off shortraker in Pacific Ocean Perch and Atka Mackerel fisheries in the AI (Ackley and Heifetz, 2001). During 1996, Shortraker Rockfish had a first wholesale price of $1.10 - 1.80 per pound, making them a relatively valuable species (Ackley and Heifetz, 2001). Between 1995 and 1996, the bycatch rate for Shortraker Rockfish and Rougheye Rockfish in the Pacific Ocean Perch fishery nearly doubled (Ackley and Heifetz, 2001). The increase in incidental catch of Shortraker Rockfish/Rougheye Rockfish suggests that "topping off" occurred when the economic value of Shortraker Rockfish/Rougheye Rockfish increased during 1996. From 1994 through 1996, 14% of 2000 rockfish hauls appeared to have targeted Shortraker Rockfish (Ackley and Heifetz, 2001). In 1996 in the GOA, Shortraker Rockfish and Rougheye Rockfish were the dominant species in the catch and, therefore, considered the target species (Ackley and Heifetz, 2001). However, it is not clear whether each case of topping off was intended, or if a particular vessel inadvertently encountered large numbers of Shortraker Rockfish early in the fishing season. Most hauls for which Shortraker

Rockfish and Rougheye Rockfish were the dominant catch occurred between Attu and Kiska islands, though there did not appear to be spatial preferences in order to encounter more Shortraker Rockfish or Rougheye Rockfish (Ackley and Heifetz, 2001). Furthermore, the locations of high densities of Shortraker Rockfish and Rougheye Rockfish overlapped with various other target species in the AI fisheries (Ackley and Heifetz, 2001).

Although catch records indicate that topping off may occur in the AI Atka Mackerel and Pacific Ocean Perch fisheries, specific data, which could improve our understanding of whether bycatch was truly incidental or was targeted up to maximum retainable bycatch (MRB) levels, are unavailable (Ackley and Heifetz, 2001). Shortraker Rockfish, as a solitary species, may be at a lower risk of being caught accidentally than more gregarious rockfish species. In a GOA survey, it was observed that aggregating rockfish, such as Northern Rockfish and Pacific Ocean Perch, had significantly higher bycatch rates in targeted rockfish fisheries than did other bycatch for these fisheries (Ackley and Heifetz, 2001). Apparent targeting of Shortraker Rockfish may result from fishermen coincidentally fishing in areas where there happened to be concentrations of Shortraker Rockfish. However, since Shortraker Rockfish are solitary, and unlikely to be found in high concentrations, it is possible that they are being targeted. Further knowledge of Shortraker Rockfish home range size and their population density in the GOA would be useful in determining the likelihood of catching a large number of Shortraker Rockfish over a relatively small area. It is imperative that further investigation of whether shortraker bycatch is primarily unintended or whether topping off is occurring.

Furthering our knowledge of economic incentives, number of hauls for individual vessels and trip duration may shed light on the target intentions of fishing operations in the GOA. If a given stock is at risk of overfishing, a large difference between natural bycatch levels and the MRB may lead to a significant decline in the stock. Since Shortraker Rockfish are a long-lived, slow-growing species, they may be inherently at a greater risk of overfishing than their short-lived counterparts. If Shortraker Rockfish are at risk of overfishing, it may be necessary to reduce the MRB to more closely reflect natural bycatch levels of Shortraker Rockfish, assuming that the "true" bycatch rate can be determined.

7.4 Northern Rockfish

7.4.1 Life History

7.4.1.1 Morphology and Distribution

Northern Rockfish (*Sebastes polyspinis*) range from the BSAI through the GOA to British Columbia (Love, 2011). They are one of the most abundant rockfish in the GOA and AI. The name *polyspinis* is Latin for "many spines", referring to the Northern Rockfish's 14 dorsal spines (other species have only 13) (Love, 2011). Northern Rockfish are a sleek-bodied reddish-pink fish with dark grey or brown mottling. They can be distinguished from other red rockfish by three dark bars radiating backward from each eye. Northern Rockfish occupy depths from 10 – 740 m but are usually found between 75 m and 200 m. Juveniles tend to inhabit relatively shallow waters and migrate to deeper waters as they mature. Northern Rockfish along the eastern AI and the GOA are larger at a given age than those found along the western Aleutians, and likely reach a larger maximum size at age (Love, 2011). Studies on other rockfish in the GOA have demonstrated that growth can vary with both latitude and longitude (Malecha et al., 2007).

7.4.1.2 Trophic Interactions

Northern Rockfish are planktivorous; they feed primarily on euphausiids and calanoid copepods in both the GOA and AI (Yang, 1993; Yang 1996; Yang and Nelson, 2000). Smaller Northern Rockfish (< 25 cm) primarily prey on calanoid copepods, whereas larger Northern Rockfish (≥ 25 cm) prey on euphausiids (Yang, 1996). Larger Northern Rockfish also consume myctophids, squids, arrow worms, hermit crabs, and shrimp (Yang, 1993; Yang, 1996; Yang, 2003). Unfortunately, little is known about abundance and trends of these prey items or whether fluctuations in abundance strongly contribute to Northern Rockfish year-class strength (Yang and Nelson, 2000; Yang, 2003; Yang et al., 2006; Clausen and Echave, 2011). Changes in water temperature and localized currents may influence the abundance of prey items. The level of predation on larval and juvenile Northern Rockfish could also significantly affect year-class strength. Predation on Northern Rockfish has not been well-documented but likely includes relatively large fish such as Pacific Halibut (Heifetz et al., 2009).

7.4.1.3 Age

Northern Rockfish are relatively short-lived compared with many other rockfish species. They have a maximum lifespan of 57 years (Munk, 2001). Northern rockfish are relatively fast-growing and quick to reach maturity compared to many other rockfish. Female Northern Rockfish reach 50% maturity at approximately 8 years (Chilton, 2007).

The sagittal otolith is commonly used for groundfish age estimates (Munk, 2001). The surface of the otolith may be examined for annuli, although this method tends to underestimate age (Munk, 2001). More accurate age estimates may be obtained from otoliths by using a “break and burn” method, in which the otolith is cut into transverse sections and one half of the otolith is lightly charred to darken the proteinaceous winter zone in each annulus (Munk, 2001). Currently efforts are underway to validate aged otoliths with radiometric aging (Munk, 2001). The ratio of lead (^{210}Pb) to radium (^{226}Ra) in the core of an otolith can be measured to estimate the age of that otolith. Radiometric aging has been used to validate otolith age estimates of Northern Rockfish in the GOA (Heifetz and Clausen, 1991; Munk, 2001).

7.4.1.4 Reproduction

Despite the abundance and commercial value of Northern Rockfish, relatively little is known about their reproduction (Chilton, 2007). Depending on location, Northern Rockfish may mature at slightly different ages because of differences in growth rate (Love et al., 2002). Nonetheless, their relatively young age at maturity compared to many other rockfish may put them at less risk of overfishing than species that mature more slowly and have less opportunity to reproduce before capture.

Northern Rockfish are viviparous (Wourms, 1991). Males may mature up to six months prior to females; and insemination may occur up to six months before fertilization (Boehlert and Yoklavich, 1984). Parturition takes place between April and June (Chilton, 2007). The fecundity of Northern Rockfish is unknown, though it has been demonstrated that smaller rockfish have substantially lower fecundities than larger species (Love et al., 2002; Clausen and Echave, 2011). Since the Northern Rockfish is considered a small- to medium-sized north Pacific rockfish, its fecundity likely falls in the lower end of the range of egg production by rockfish (Love et al., 2002). Fecundity among 33 northeast Pacific rockfish ranges from approximately 18,000 eggs in the Dwarf Calico Rockfish (*Sebastes dallii*) to 2,700,000 in the Yelloweye Rockfish (Love et al., 2002). Since Northern Rockfish are over twice the size of Dwarf Calico Rockfish and are approximately half the size of Yelloweye Rockfish, it is likely that their fecundity falls within this range (Butler et al., 2012).

7.4.1.5 Larval and Juvenile Stages

Little information is available on the habitat of juvenile Northern Rockfish. It is difficult to assess the abundance and distribution of rockfish larvae, since numerous rockfish species have morphologically similar larvae (Spencer and Reuter, 2008). Studies in the eastern GOA and Southeast Alaska that deployed trawls and submersibles have indicated that several species of juvenile (< 20 cm) red rockfish (*Sebastes* spp.) associate with benthic nearshore living and non-living structure (Carlson and Straty, 1981; Krieger, 1992). Freese and Wing (2003) also identified juvenile (5 to 10 cm) red rockfish associated with sponges (primarily *Aphrocallistes* sp.) attached to boulders. The juvenile red rockfish appeared to be using the sponges as shelter

(Freese and Wing, 2003). Although these studies did not specifically observe Northern Rockfish, it is likely that juvenile Northern Rockfish use similar habitats (Heifetz et al., 2009). Older juvenile Northern Rockfish (> 20 cm) generally are found on the continental shelf further inshore than their adult counterparts (Heifetz et al., 2009).

7.4.1.6 Habitat Preferences

Adult Northern Rockfish in the GOA prefer relatively shallow banks on the outer continental shelf at depths of 75 - 150 m (Clausen and Heifetz, 2002). Northern Rockfish inhabit rocky, steep substrate. They are also thought to associate with gorgonian corals (primarily *Callogorgia*, *Primnoa*, *Paragorgia*, *Fanellia*, *Thouarella*, and *Arththrogorgia*) (Krieger and Wing, 2002). However, Northern Rockfish have not been documented among gorgonians (Heifetz et al., 2009). Further research of Northern Rockfish habitat preferences is needed because changes in their environment could influence the ability of Northern Rockfish to find shelter from predators and to catch prey in addition to affecting them physiologically.

7.4.1.7 Biomass Estimates in the Bering Sea/Aleutian Islands

The U.S. and Japan conducted joint trawl surveys from 1979 through 1985 in the Bering Sea and from 1980 through 1986 in the AI to obtain biomass estimates for red rockfish, including Northern Rockfish. Following the cessation of foreign commercial fishing in Alaskan waters, the U.S. conducted trawl surveys without the participation of Japan. The U.S domestic trawl surveys were conducted in 1988, 1991, 2002, 2004, 2008, and 2010 in the EBS, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, and 2010 in the AI (Spencer and Rooper, 2010). The AI survey scheduled for 2008 was canceled to due lack of funding (Spencer and Ianelli, 2012). Survey abundance in the western and central AI was larger from 1991 - 2012 than in the eastern AI and EBS. Areas of particularly high biomass estimates were Amchitka Island, Kiska Island, Buldir

Island, and Tahoma Bank (Spencer and Ianelli, 2012). The 2012 AI survey biomass was 285,164 t, which represents an increase of 31% from the 2010 estimate of 217,319 t (Figure 1). Much of this increase occurred in the western AI.

The biennial EBS slope survey was initiated in 2002 and may help to provide more accurate biomass estimates of Northern Rockfish in the BSAI when coupled with AI survey data. The most recent EBS survey prior to 2002, excluding preliminary tows in 2000 intended to evaluate survey gear, was in 1991. The EBS slope survey biomass estimates of Northern Rockfish from the 2002 - 2012 surveys ranged between 3 t (2008 and 2012) and 42 t (2010) (Spencer and Ianelli, 2012).

7.4.1.8 Biomass Estimates in the Gulf of Alaska

Bottom trawl surveys were conducted in the GOA triennially from 1984-1999 and became biennial surveys starting in 1999 (Hulson et al., 2013). These surveys have provided substantial data on Northern Rockfish biology, including abundance trends and size composition. Trawl survey biomass estimates for Northern Rockfish in the GOA have been highly variable (Hulson et al., 2013). In 2003, the biomass estimate was 66,310 t. In 2005, the biomass estimate increased to 358,998 t. The biomass estimate in 2007 decreased to 227,069 t, and continued to decrease to 89,896 t in 2009. In 2011, the biomass estimate increased to 173,642 t. The 2013 biomass estimate (370,454 t) is the highest estimated biomass since 1993 (Figure 1). The increase in estimated biomass in 2013 is explained by a three-fold increase in estimated biomass in the Chirikof region (Hulson et al., 2013).

Such large fluctuations in biomass do not seem probable given the relatively long life, slow growth, low natural mortality, late maturity, and modest level of commercial catch of Northern Rockfish. The precision of some of the survey biomass estimates has been low and is reflected in the large 95% confidence intervals and high coefficients of variation associated with some estimates (Hulson et al., 2013). The highly variable biomass estimates for Northern Rockfish indicate that an alternative to the stratified random sampling design may be needed to reduce the variability in biomass estimates.

7.4.1.9 Population Structure

There have been relatively few known localized depletions for Northern Rockfish (Hanselman et al., 2007). However, several significant depletions occurred in the early 1990s for Northern Rockfish. If fine-scale stock structure is determined in Northern Rockfish, then the current apportionment of ABC may not be sufficient to protect Northern Rockfish from localized depletion. If there is relatively small-scale stock structure (120 km) in Gulf of Alaska Northern Rockfish, then recovery from localized depletion could be slow. The maintenance of spatial distribution of recruitment is essential for long-term sustainability of exploited rockfish populations (Berkeley et al., 2004). Limited larval dispersal suggests that genetic heterogeneity in rockfish may be the result of stock structure (Heifetz et al., 2009).

A stock structure evaluation for Northern Rockfish was constructed from microsatellite data from 2004 samples from the EBS and AI (Gharrett et al., 2012). Three genetically distinct groups were identified: 1) the EBS; 2) two collections west of Amchitka Pass; and 3) three collections between Amchitka Pass and Unimak Pass. The genetic data also indicate a statistically significant pattern of isolation by distance, suggesting that genetic structure amongst Northern Rockfish subpopulations is from the dispersal of individuals that is smaller than the spatial extent of the sampling locations (Gharrett et al., 2012; Spencer and Ianelli, 2012). The estimated lifetime dispersal distances did not exceed 250 km for Northern Rockfish, which indicates that Northern Rockfish have relatively small home ranges within the BSAI geographic range.

The population structure of Northern Rockfish in Alaskan waters may be attributable to physical barriers. If larval dispersal and adult movement are restricted, then the structure may reflect geographic segregation. Oceanographic features such as eddies and onshore currents may retain larvae and prevent their dispersal or disperse them at different times (Owen, 1980; Wing et al., 1998; Spencer and Ianelli, 2012). The Alaska Stream separates from the slope west of the Amchitka pass and may form eddies, potentially limiting the connection between the eastern and the western Aleutians. Deep trenches in the AI exceeding 500 m in depth may limit the dispersal of Northern Rockfish (Spencer and Ianelli, 2012). Adult Northern Rockfish are demersal and inhabit depths of 100 - 200 m so it is unlikely that they would traverse pelagic habitat or deeper depths found in these trenches. Behavior of juveniles during settlement could further promote local retention since many rockfish become relatively stationary once they reach adulthood (Larson et al., 1994; Drake et al., 2010).

In order to more fully understand Northern Rockfish population structure, there should be further study of Northern Rockfish life history characteristics, particularly age composition, age at maturity, and size at age. Northern Rockfish biological data, such as identification and distribution of their larvae, average and maximum fecundities, and breeding habits, may assist in promoting effective management and conservation strategies. It is imperative that further studies of Northern Rockfish and other rockfish are undertaken in order to minimize the risk of eventually overfishing their populations.

7.4.2 Management

7.4.2.1 Management in the Bering Sea/Aleutian Islands

The management of Northern Rockfish in the EBS and AI management areas began in 1977 (Spencer and Ianelli, 2012). Northern Rockfish were managed in the EBS and AI within the “other species” regulatory complex during 1977 and 1978. They were included in the Pacific Ocean Perch complex from 1979-1985, and 1989. Northern Rockfish were reported under “rockfish without Pacific Ocean Perch” between 1986 and 1988 in the BSAI (Spencer and Ianelli, 2012). From 1991-2000, Northern Rockfish were managed under the “other red rockfish” category in the EBS, whereas in the AI they were managed in the Northern Rockfish/Sharpchin Rockfish category. In 2001, Northern Rockfish in the EBS were removed from the “other red rockfish” complex to be managed solely with Sharpchin Rockfish. In 2001 EBS Northern Rockfish and AI Northern Rockfish were assessed and managed jointly across the BSAI region (Spencer and Ianelli, 2012). In 2002 Sharpchin Rockfish were removed from the red rockfish EBS and AI regulatory complexes and placed in the “other slope rockfish” management category (Clausen and Echave, 2011). In 2002, Northern Rockfish began to be managed separately because the catches of Sharpchin Rockfish were negligible (Spencer and Ianelli, 2012). From 2002-2013 Northern Rockfish has been managed as its own category in the BSAI and will likely continue to be managed as such in subsequent years.

7.4.2.2 Management in the Gulf of Alaska

In 1988 in the federal waters in the GOA, rockfish were divided into three groups based on their general habitat preferences as adults (Clausen et al., 2011). Northern Rockfish were originally assessed as part of the “slope rockfish” complex, along with 15 other rockfish species (Clausen and Echave, 2011; Hulson et al., 2013). In 1991, the NPFMC divided the slope rockfish assemblage in the GOA into three management subgroups: Pacific Ocean Perch, Shortraker Rockfish/Rougheye Rockfish, and a complex of all other species of slope rockfish, including Northern Rockfish. In 1993, Northern Rockfish was removed from the slope rockfish complex to be managed separately (Hulson et al., 2013).

The ABC and TAC for Northern Rockfish is divided amongst three management areas within the GOA (Western, Central, and Eastern) based on a weighted average of the proportion of biomass by area from the three most recent Gulf of Alaska trawl surveys (Hulson et al., 2013). Northern Rockfish are relatively scarce in the eastern GOA, and a small ABC and TAC are assigned to this region (Hulson et al., 2013). In 2006, NMFS implemented the Central GOA Rockfish Pilot Program in order to enhance resource conservation and to improve economic efficiency for fishermen in the rockfish fishery (Hulson et al., 2013). The primary rockfish management groups in this program are Northern Rockfish, Pacific Ocean Perch, and pelagic shelf rockfish. This program will: extend the Northern Rockfish fishing season, change the spatial distribution of fishing effort within the central GOA, improve observer coverage for vessels participating in the rockfish fishery, and provide a greater opportunity to harvest 100% of the TAC in the central GOA (Hulson et al., 2013)

7.4.2.3 Catch Trends

Foreign fisheries did not report Northern Rockfish as a single species but included them within management categories such as “other species” (1977 and 1978), “Pacific Ocean Perch complex” (1979–1985, 1989), and “rockfish without Pacific Ocean Perch” (1986–1988) (Spencer and Ianelli, 2012). Catches of Northern Rockfish were relatively high in the late 1970s, and declined in the late 1980s as the foreign fishery was vastly reduced. Northern Rockfish catch during 1980-1990 was small relative to more recent years. According to harvest data from 2004-2012, approximately 84% of the BSAI Northern Rockfish were harvested in the Atka mackerel fishery (Hulson et al., 2013). Northern Rockfish was managed under tier 5 until 2004, after which there was sufficient biological data available for Northern Rockfish to be managed under tier 3 (Spencer and Ianelli, 2012).

Although Northern Rockfish are not currently considered overfished, relatively little is known about the reproductive biology and population structure of this species, which puts it at potential risk of overfishing. The implementation of marine reserves in the GOA may provide an effective conservation strategy for rockfish such as Northern Rockfish in the future (Soh et al., 2001). However, the effectiveness of the proposed reserves would be contingent upon whether they are placed in areas that have a consistently high concentration of Northern Rockfish and whether these areas were previously heavily fished.

7.4.2.4 Incidental Catch

Data on the proportion of discarded Northern Rockfish are generally not available in years when the management categories consist of multi-species complexes. However, because the catches of Sharpchin Rockfish are relatively small, the discard information available for the "sharpchin/northern" complex can interpreted as Northern Rockfish discards (Hulson et al., 2013). Prior to 2003, discard rates were typically above 80% (Hulson et al., 2013). Recently, discard rates have been decreasing. For example, the discard rate in the EBS has declined from 92% in 2002 to 15% in 2011, and the discard rate in the Aleutian Islands has declined from 91% to 18% over the same period (Hulson et al., 2013).

Northern Rockfish are primarily caught in bottom trawls. From 1990-1998, 89% of Northern Rockfish catch was from five relatively small fishing grounds: Portlock Bank, Albatross Bank, an unnamed bank south of Kodiak Island that fishermen commonly refer to as the "Snakehead," Shumagin Bank, and Davidson Bank (Clausen and Heifetz, 2002). All of these grounds can be characterized as relatively shallow (75 – 150 m) offshore banks on the outer continental shelf. During this time period 82% of the Northern Rockfish catch was from directed fishing efforts, while 18% was taken as incidental catch (Clausen and Heifetz, 2002).

7.5 Dusky Rockfish

7.5.1 Life History

7.5.1.1 Morphology and Distribution

Dusky Rockfish (*Sebastes variabilis*) have one of the most northerly distributions, ranging from southern British Columbia to the Bering Sea and Hokkaido Island, Japan. However, they appear to be most abundant in the GOA. Adult Dusky Rockfish are typically found on the outer continental shelf at depths of 100-200 m (Reuter, 1999). Submersible surveys in the GOA showed that Dusky Rockfish appear to associate with biogenic rocky habitat. Dusky Rockfish were observed in association with both sponges and small *Primnoa* coral species (Krieger and Wing, 2002; Freese and Wing, 2003).

Dusky Rockfish are light to medium grey in color. They can reach a maximum length of 59 cm and a maximum weight of 3 kg (Love, 2011). Dusky rockfish are larger in deep water in the BSAI than their conspecifics in shallower waters (Love, 2011). The observed size difference with depth may be because of different cohorts occupying varied depths/locations given that older, larger Dusky Rockfish are known to occupy deeper water than younger, smaller ones. However, difference in size at depth between these locations could be a function of spatial variation in growth rates at a given age. Studies on other rockfish in the GOA have demonstrated that growth can vary with both latitude and longitude (Malecha et al., 2007).

7.5.1.2 Trophic Interactions

Adult Dusky Rockfish primarily feed on euphausiids and Sandlance (*Ammodytes hexapterus*) (Yang et al., 2006). Euphausiids comprise approximately 82% of their diet and Sandlance comprise approximately 17% of their diet. They also consume copepods, larvaceans, gammarid amphipods, arrow worms, shrimps, cephalopods, and fish (Love, 2011). Unfortunately, little is known about trends in abundance of most of these prey items or whether fluctuations in abundance strongly contribute to year-class strength (Yang and Nelson, 2000; Yang, 2003; Yang et al., 2006; Clausen and Echave, 2011). Changes in water temperature and localized currents may influence the abundance of prey items. The level of predation on larval and juvenile Dusky Rockfish could also significantly affect year-class strength. Unfortunately there is no documentation of predation on Dusky Rockfish (Clausen et al., 2003). Pacific Halibut are known to feed on other rockfish and may also prey on adult Dusky Rockfish, but the level of predation is likely minimal (Clausen et al., 2003).

7.5.1.3 Age

Dusky Rockfish live up to 76 years (Love, 2011). As a long-lived species, the Dusky Rockfish is slow to reach maturity relative to shorter-lived fish. In the GOA, female Dusky Rockfish reach 50% maturity at age 9 (Love, 2011).

7.5.1.4 Reproduction

Depending on location, Dusky Rockfish may mature at slightly different ages because of differences in growth rate (Love et al., 2002). Nonetheless, their old age at maturity relative to other rockfish may put them at a greater risk of overfishing than fish species that mature more quickly and have greater opportunity to reproduce before capture. However, their generation time is shorter relative to other long-lived, deep-dwelling rockfish (Lunsford et al., 2011).

Dusky Rockfish are viviparous (Lunsford et al., 2011). Parturition occurs from April-July in the GOA (Love, 2011; Lunsford et al., 2011). Although post-larval Dusky Rockfish have not been observed, it is likely that the early juvenile stage is pelagic, similar to other *Sebastes* species. Eventually, juvenile Dusky Rockfish assume a demersal existence (Lunsford et al., 2011).

The fecundity of Dusky Rockfish is unknown, though it has been demonstrated that larger rockfish have substantially higher fecundities than smaller species (Love et al., 2002; Clausen and Echave, 2011). Fecundity among 33 northeast Pacific rockfish ranges from approximately 18,000 eggs in the Dwarf Calico Rockfish (*Sebastes dallii*) to 2,700,000 in the Yelloweye Rockfish (Love et al., 2002). Larger, older female spawners within a given rockfish species have a higher fecundity and higher larval than their smaller counterparts (Berkeley et al., 2004; Bobko and Berkeley, 2004). However, such relationships have not yet been determined to exist for Dusky Rockfish; thus, stock assessments for Dusky Rockfish have assumed that the reproductive success of Dusky Rockfish is independent of age (Lunsford et al., 2013).

7.5.1.5 Larval and Juvenile Stages

Dusky Rockfish larvae are pelagic, but it is unknown when juveniles in the GOA assume a demersal existence (Love et al., 2002). It is difficult to assess the abundance and distribution of rockfish larvae, since numerous rockfish species have morphologically similar larvae (Spencer and Reuter, 2008).

7.5.1.6 Habitat Preferences

Adult Dusky Rockfish are most common at depths between 100 m and 200 m and are often found along the outer continental shelf (Reuter, 1999). Both adult and juvenile Dusky Rockfish have been observed in association with boulders that had attached sponges. Adults have also been observed resting inside large vase sponges (Freese and Wing, 2003). Submersible studies have also observed small Dusky Rockfish inhabiting rocky areas containing *Primnoa* spp. corals (Krieger and Wing, 2002).

7.5.1.7 Biomass Estimates in the Gulf of Alaska

Bottom trawl surveys were conducted in the GOA triennially from 1984 through 1999 and became biennial surveys starting in 2001 (Lunsford et al., 2013). These surveys have provided substantial data on Dusky Rockfish abundance trends (Lunsford et al., 2013). Dusky Rockfish were separated into light and dark varieties in 1996, and in 2004 these two varieties were identified as separate species, Dusky and Dark Rockfish, respectively (Lunsford et al., 2013). It is presumed that the Dusky Rockfish biomass estimates from surveys prior to 1996 consisted primarily of Dusky Rockfish, rather than of Dark Rockfish.

Data from the surveys have shown that the biomass of Dusky Rockfish in the GOA has fluctuated widely during the last three decades. Total estimated biomass increased from 1984 through 1987, and then decreased by over 50% in 1990. Estimated biomass increased from 1993 through 1996, then decreased again from 1999 through 2001. It increased by over 2.5 fold from 2003 to 2005, decreased from 2007 to 2009, then increased from 2011 to 2013 (Figure 1). These survey results suggest that Dusky Rockfish have a patchy and highly aggregated distribution (Lunsford et al., 2013).

7.5.1.8 Population Structure

Dusky Rockfish were originally classified as two color morphs, named “dark dusky” and “light dusky” rockfish. They have since been classified as two separate species (Orr and Blackburn, 2004). The Dark Rockfish occurs in shallow water, and the Dusky Rockfish occurs in relatively deeper water. Dusky Rockfish have patchy, highly aggregated distribution, which could result in genetically differentiated populations (Lunsford et al., 2011). However, the little available data for Dusky Rockfish suggests a lack of significant stock structure (Lunsford et al., 2013).

7.5.2 Management

In 1988, in the federal waters in the GOA, rockfish were divided into three groups based on their general habitat preferences as adults (Clausen et al., 2011). Dusky Rockfish were originally assessed as part of the “pelagic shelf rockfish assemblage” (Lunsford et al., 2013). Widow Rockfish and Yellowtail Rockfish are managed under tier 5, while Dusky Rockfish are managed under tier 3a. In 2012, Widow and Yellowtail Rockfish were removed from the pelagic shelf assemblage, leaving Dusky Rockfish to be assessed and managed as a separate species (Lunsford et al., 2013).

7.5.2.1 Catch Trends

Catch reconstruction for Dusky Rockfish is difficult because, until recently, Dusky Rockfish were managed as part of the pelagic rockfish assemblage (Lunsford et al., 2013). There are catch data for Dusky Rockfish in the GOA from 1977 through 2013. Annual catch of Dusky Rockfish in the GOA increased from 1988 through 1992, and fluctuated during subsequent years. As TACs became more restrictive during the 1990s, Dusky Rockfish became more targeted by fishermen. However, each year a large amount of un-harvested catch remained for the Dusky Rockfish fishery, probably because of early closures of the rockfish fishery to prevent exceeding the TAC on other species, such as Pacific Ocean Perch, or to prevent excess bycatch of Pacific Halibut (Lunsford et al., 2013).

7.5.2.2 Incidental Catch

Most of the incidental catch of Dusky Rockfish occurred in hauls targeting Northern Rockfish (Ackley and Heifetz, 2001). Groundfish bycatch in the central GOA has been reduced since 2007 (Lunsford et al., 2013). Dusky Rockfish are often associated with other rockfish species such as Northern Rockfish, Pacific Ocean Perch, and Harlequin Rockfish (Reuter, 1999).

7.6 References for Appendix

Ackley D. R., and J. Heifetz.

2001. Fishing practices under maximum retainable bycatch rates in Alaska’s groundfish fisheries. Alaska Fish. Res. Bull. 8:22-44.

Ainley, D. G., W. J. Sydeman, R. H. Parrish, and W. H. Lenarz.

1993. Oceanic factors influencing distribution of young rockfish (*Sebastes*) in central California: A predator’s perspective. Calif. Coop. Ocean. Fish. Invest. Rep 34:133-139.

Alaska Fisheries Science Center (AFSC).

2011. NMFS-NOAA Fisheries. http://www.afsc.noaa.gov/ABL/MESA/mesa_sa_rock.htm

Alverson, D. L., and J. Westrheim.

1961. A review of the taxonomy and biology of the Pacific ocean perch and its fishery. Cons. Perm. Internat. Explor. Rapp. Proc-Verb. 150:169-176.

Barsukov, V. V.

1970. Species composition of the genus *Sebastes* in the North Pacific. Description of a new species. Dokl. Acad. Nauk SSSR Ser. Biol. 195:994-997.

Berger, J. D, J. E. Smoker, and K. A. King.

1986. Foreign and joint venture catches and allocations in the Pacific Northwest and Alaska fishing area under the Magnuson Fishery Conservation and Management Act, 1977-84. NOAA Tech. Memo. NMFS F/NWC-99, 53p.

Berkeley, S. A., C. Chapman, and S. M. Sogard.

2004. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85:1258-1264.

Berkeley, S. A., and D. Markle.

1999. Effects of fishing-induced age truncation on recruitment and reproductive potential in black rockfish (*Sebastes melanops*). Final report to Oregon Sea Grant, R/OPF-46, 5 p.

Bobko, S. J., and S. A. Berkeley.

2004. Maturity, ovarian cycle, fecundity, and age-specific parturition of black rockfish (*Sebastes melanops*). Fish. Bull. 102:418-429.

Boehlert, G. W., and M. M. Yoklavich.

1984. Variability in age estimates in Sebastes as a function of methodology, different readers, and different laboratories. Calif. Fish Game. 70:210-224.

Boldt, J. L., and C. Rooper.

2009. Abundance, condition, and diet of juvenile Pacific ocean perch (*Sebastes alutus*) in the Aleutians Islands. Fish. Bull. 107:278–285.

Botsford, L. W., C. L. Moloney, A. Hastings, J. L. Largier, T. M. Powell, K. Higgins, and J. F. Quinn.

1994. The influence of spatially and temporally varying oceanographic conditions on meroplanktonic metapopulations. Deep-Sea Res. Part II: Top. Stud. Oceanogr. 41:107–145.

Brodeur, R. D.

2000. Habitat-specific distribution of Pacific ocean perch (*Sebastes alutus*) in Pribilof Canyon, Bering Sea. Cont. Shelf. Res. 21:207-224.

Buonaccorsi, V. P., C. A. Kimbrell, E. A. Lynn, and D. V. Russell.

2005. Limited realized dispersal and introgressive hybridization influence genetic structure and conservation strategies for brown rockfish, *Sebastes auriculatus*. Cons. Gen. 6:697-713.

Butler, J. S., M. S. Love, and T. E. Laidig.

2012. A guide to the rockfishes, thornyheads, and scorpionfishes of the Northeast Pacific. 200 p. Univ. California Press, Berkeley, CA.

Cailliet, G. M., A. H. Andrews, E. J. Burton, D. L. Watters, D. E. Kline, and L. A. Ferry-Graham.

2001. Age determination and validation studies of marine fish; do deep-dwellers live longer? Exp. Gerontology 36:739-764.

Carlson, H. R., and R. E. Haight.

1976. Juvenile life of Pacific ocean perch, *Sebastes alutus*, in coastal fjords of southeastern Alaska: their environment, growth, food habits, and schooling behavior. Trans. Am. Fish. Soc. 105:191-201.

Carlson H. R., and R. R. Straty.

1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky coastal areas of Southeastern Alaska. Mar. Fish. Rev. 43:13-19.

Chilton, E.

2007. Maturity of female northern rockfish *Sebastes polyspinis* in the Central Gulf of Alaska. Alaska Fish. Res. Bull. 12:264-269.

Chitwood, P. E.

1969. Japanese, Soviet, and South Korean fisheries off Alaska, development and history through l966. U.S. Fish. Wildl. Serv. Circ. 310, 34 p.

Clausen, D. M.

2004. Alternative ABC's for shortraker/rougheye rockfish in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources for the 2004 Gulf of Alaska groundfish fishery, p. 416-428. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Clausen, D. M.

2009. Assessment of shortraker rockfish and "other slope rockfish". *In* Stock assessment and fishery evaluation report for the 2009 Gulf of Alaska groundfish fishery, p. 875-924. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Clausen D. M., and K. B. Echave.

2011. Assessment of the "other slope rockfish" stock complex in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 1239-1280. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Clausen, D. M., and J. T. Fujioka.

2007. Variability in trawl survey catches of Pacific ocean perch, shortraker rockfish, and rougheye rockfish in the Gulf of Alaska. *In* Biology, assessment, and management of North Pacific rockfishes (J. Heifetz, J. DiCosimo, A. J. Gharrett, M. S. Love, V. M. O'Connell, and R. D. Stanley, eds.), p. 411-428. Alaska Sea Grant Press, Fairbanks, AK.

Clausen, D. M., J. T. Fujioka, and J. Heifetz.

2003. Shortraker/rougheye and other slope rockfish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the GOA, p. 531-572. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Clausen, D., and J. Heifetz.

2002. The northern rockfish, *Sebastes polyspinis*, in Alaska: commercial fishery, distribution, and biology. Mar. Fish. Rev. 64:1-28.

Clausen D., T. Pearson, and C. Lunsford.

2011. Management reorganization of species in the Gulf of Alaska pelagic shelf rockfish and “other slope rockfish” assemblages. Discussion paper for Gulf of Alaska groundfish plan team, 12 p. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Conover, D. O., L. M. Clarke, S. B. Munch, and G. N. Wagner.

2006. Spatial and temporal scales of adaptive divergence in marine fishes and the implications for conservation. J. Fish Biol. 69:21–47.

Cooper, D. W., K. E. Pearson, and D. R. Gunderson.

2005. Fecundity of shortspine thornyhead (*Sebastolobus alascanus)* and longspine thornyhead (*S. altivelis)* (Scorpaenidae) from the northeastern Pacific Ocean, determined by stereological and gravimetric techniques. Fish. Bull. 103:15-22.

Cope, J. M.

2004. Population genetics and phylogeography of the blue rockfish (*Sebastes mystinus)* from Washington to California. Can. J. Fish. Aquat. Sci. 61:332–342.

Drake J. S., E. A. Berntson, J. M. Cope, R. G. Gustafson, E. E. Holmes, P. S. Levin, N. Tolimieri, R. S. Waples, S. M. Sogard, and G. D. Williams.

2010. Status review of five rockfish species in Puget Sound, Washington: bocaccio rockfish (*Sebastes paucispinis*), canary rockfish (*S. pinniger*), yelloweye rockfish (*S. ruberrimus*), greenstriped rockfish (*S. elongatus*), and redstripe rockfish (*S. proriger*). NOAA Tech. Memo. NMFS-NWFSC-108, 234 p.

Eschmeyer, W. N., E. S. Herald, and H. Hammann.

1983. A Field Guide to Pacific Coast Fishes, 336 p. Houghton Mifflin Co, Boston MA.

Freese, J. L., and B. L. Wing.

2003. Juvenile red rockfish, *Sebastes* sp., associations with sponges in the Gulf of Alaska. Mar. Fish. Rev. 65:38-42.

Gaichas, S., and J. Ianelli.

2003. Thornyheads. *In* Stock assessment and fishery evaluation report for the 2003 Gulf of Alaska groundfish fishery, p. 659-698. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Garoia, F., I. Guarniero, C. Piccinett, and F. Tinti.

2004. First microsatellite loci of red mullet (*Mullus barbatus*) and their application to genetic structure analysis of Adriatic shared stock. Mar. Biotechnol. 6:1436-2236.

Gharrett, A. J., A. K. Gray, and J. Heifetz.

2001. Identification of rockfish (Sebastes spp.) from restriction site analysis of the mitochondrial DNA ND-3/ND-4 and 12S rRNA regions. Fish. Bull. 99:49-62.

Gharrett, A. J., A. P. Matala. E. L. Peterson, A. K. Gray, Z. Li, and J. Heifetz.

2005. Two genetically distinct forms of rougheye rockfish are different species. Trans. Am. Fish. Soc. 134:242-260.

Gharrett, A. J., R. J. Riley, and P. D. Spencer.

2012. Genetic analysis reveals restricted dispersal of northern rockfish along the continental margin of the Bering Sea and Aleutian Islands. Trans. Am. Fish. Soc. 141:370-382.

Gunderson, D. R.

1977. Population biology of Pacific ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte sound region, and their response to fishing. Fish. Bull. 75: 369-403.

Gunderson, D. R.

1997. Spatial patterns in the dynamics of slope rockfish stocks and their implications for management. Fish. Bull. 95:219-230.

Haldorson, P. E. L., and K. Krieger.

2002. Shortspine thornyhead (*Sebastolobus alascanus)* abundance and habitat associations in the Gulf of Alaska. Fish. Bull. 100:193–199.

Hanselman, D., J. Heifetz, J. T. Fujioka, and J. N. Ianelli.

2005. Gulf of Alaska Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the 2005 Gulf of Alaska groundfish fishery, p. 525-578. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hanselman, D., J. Heifetz, J. T. Fujioka, and S. K. Shotwell, J. N. Ianelli.

2007. Gulf of Alaska Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the 2007 Gulf of Alaska groundfish fishery, p. 570-622. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hanselman, D. H., T. J. Quinn, C. Lunsford, J. Heifetz, and D. M. Clausen.

2003. Applications in adaptive cluster sampling of Gulf of Alaska rockfish. Fish. Bull. 101:501–512.

Hanselman, D., S. K. Shotwell, J. Heifetz, J. T. Fujioka, and J. N. Ianelli.

2009. Gulf of Alaska Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the 2009 Gulf of Alaska Pacific groundfish fishery, p. 743-816. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hanselman, D., S. K. Shotwell, P. J. F. Hulson, J. Heifetz, and J. N. Ianelli.

2011. Gulf of Alaska Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 821-892. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hawkins S. L., J. Heifetz, C. M. Kondzela, J. E. Pohl, and R. L. Wilmot.

2005. Genetic variation of rougheye rockfish (*Sebastes aleutianus*) and shortraker rockfish (*Sebastes borealis*) inferred from allozymes. Fish. Bull. 103:524-535.

Heifetz, J, and D. M. Clausen.

1991. Slope rockfish. *In* Stock assessment and fishery evaluation report for the 1992 Gulf of Alaska groundfish fishery, p. 1-30. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Heifetz, J., D. Hanselman, J. Ianelli, S. K. Shotwell, and C. Tribuzio.

2009. Assessment of the northern rockfish stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 817-874. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hobson, E. S., J. R. Chess, and D. F. Howard.

2001. Interannual variation in predation on first-year *Sebastes* spp. by three northern California predators. Fish. Bull. 99:292-302.

Hulson, P. J. F., J. Heifetz, D. H. Hanselman, S. K. Shotwell, and J. N. Ianelli

2013. Assessment of the northern rockfish stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2013 Gulf of Alaska groundfish fishery, p. 833-904. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Hutchinson C. E.

2004. Using radioisotopes in the age determination of shortraker (*Sebastes borealis*) and canary (*Sebastes pinniger*) rockfish. M.S. thesis, 204 p. Univ. Washington, Seattle, WA.

Ito, D. H.,

1986. Status and future prospects for the Pacific ocean perch resource in waters off Washington and Oregon as assessed in 1986. NOAA-NWAFC Tech. Memo. NMFS, F/NWC-113, 50 p.

Jordan, D. S., and B. W. Evermann.

1898. The fishes of North and Middle America: a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the Isthmus of Panama, Part III. Bull. U.S. Natl. Mus. 47:2183-3136.

Kamin, L. M., K. J. Palof, J. Heifetz, and A. J. Gharrett.

2014. Interannual and spatial variation in the population genetic composition of young-of-the-year Pacific ocean perch (*Sebastes alutus*) in the Gulf of Alaska. Fish. Oceanogr. 23:1-17.

Kastelle, C. R., D. K. Kimura, and S. R. Jay.

2000. Using $^{210}Pb/^{226}Ra$ disequilibrium to validate conventional ages in Scorpaenids (genera *Sebastes* and *Sebastolobus*). Fish. Res. 46:299-312.

Kline, D. E.

1996. Radiochemical age verification for two deep-sea rockfishes *Sebastolobus altivelis* and *S. alascanus*. M.S. thesis, 124 p. San Jose State Univ. San Jose, CA.

Krieger, K. J.

1992. Shortraker rockfish, *Sebastes borealis,* observed from a manned submersible. Mar. Fish. Rev. 54:34–36.

Krieger, K. J., and D. H. Ito.

1999. Distribution and abundance of shortraker rockfish, *Sebastes borealis*, and rougheye rockfish, *S. aleutianus,* determined from a manned submersible. Fish. Bull. 97:264-272.

Krieger, K. J., and B. L. Wing.

2002. Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. Hydrobiology 471: 83-90.

Larson, R. J., W. H. Lenarz, and S. Ralston.

1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. Calif. Coop. Ocean. Fish. Invest. Rep. 35:175–219.

Leaman, B. M.

1991. Reproductive styles and life history variables relative to exploitation and management of *Sebastes* stocks. Environ. Biol. Fish. 30:253–271.

Leaman, B. M., and R. J. Beamish.

1984. Ecological and management implications of longevity in some Northeast Pacific groundfishes. Int. N. Pac. Fish. Comm. Bull. 42:85–97.

Leaman, B. M., and Z. Kabata.

1987. *Neobrachiella robusta* (Wilson 1912) (Copepoda Lernacopepodidae) as a tag for identification of stocks of its host, *Sebastes alutus* (Gilbert 1890) (Pisces: Teleostei). Can. J. Zool. 65: 2579-2582.

Logerwell, E. A., K. Aydin, S. Barbeaux, E. Brown, M. E. Conners, S. Lowe, J. W. Orr, I. Ortiz, R. Reuter, and P. Spencer.

2005. Geographic patterns in the demersal ichthyofauna of the Aleutian Islands. Fish. Oceanogr. 14:93-112.

Love, M. S.

1996. Probably more than you wanted to know about the fishes of the Pacific coast, 386 p. Really Big Press, Santa Barbara, CA.

Love, M. S.

2011. Certainly more than you want to know about the fishes of the Pacific coast, 575 p. Really Big Press, Santa Barbara, CA.

Love, M. S., M. H. Carr, and L. J. Haldorson.

1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environ. Biol. Fish. 30:225-243.

Love, M. S., M. Yoklavich, and L. Thorsteinson.

2002. The rockfishes of the northeast Pacific, 405 p. Univ. of California Press, Berkeley, CA.

Lunsford, C. R.

1999. Distribution patterns and reproductive aspects of Pacific ocean perch (*Sebastes alutus*) in the Gulf of Alaska. M.S. thesis, 145 p. Univ. Alaska Fairbanks, AK.

Lunsford, C., L. Haldorson, J. T. Fujioka, and T. J. Quinn II.

2001. Distribution patterns and survey design considerations of Pacific ocean perch (*Sebastes alutus*) in the Gulf of Alaska. *In* Spatial Processes and Management of Marine Populations (G. H. Kruse, N. Bez, A. Booth, M. W. Dorn, S. Hills, R. N. Lipcius, D. Pelletier, C. Roy, S. J. Smith, and D. Witherell, eds.), p. 1:281-302. Alaska Sea Grant Press, Fairbanks AK.

Lunsford, C. R., S. K. Shotwell, P. F. Hulson, and D. H. Hanselman.

2011. Assessment of dusky rockfish in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 1009-1104. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Lunsford, C. R., S. K. Shotwell, P. F. Hulson, and D. H. Hanselman.

2013. Assessment of dusky rockfish in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 909-974. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Major, R. L., and H. H. Shippen.

1970. Synopsis of biological data on Pacific ocean perch, *Sebastodes alutus.* FAO Fisheries Synopsis No. 79, NOAA Circular 347, 38 p.

Malecha, P. W., D. H. Hanselman, and J. Heifetz.

2007. Growth and mortality of rockfishes (Scorpaenidae) from Alaska waters. NOAA Tech. Memo. NMFS-AFSC-172, 62 p.

Matala, A. P., A. K. Gray, J. Heifetz, and A. J. Gharrett.

2004. Population structure of Alaskan shortraker rockfish, *Sebastes borealis,* inferred from microsatellite variation. Environ. Biol. Fish. 69:201-210.

McDermott, S. F.

1994. Reproductive biology of rougheye and shortraker rockfish. *Sebastes aleutianus* and *Sebastes borealis*. M.S. thesis, 76 p. Univ. Washington, Seattle, WA.

Mecklenberg, C. W., T. A. Mecklenberg, and L. K. Thorsteinson.

2002. Fishes of Alaska, 1037 p. American Fisheries Society, Bethesda, Maryland.

Miller, A. K., and W. J. Sydeman.

2004. Rockfish response to low-frequency ocean climate change as revealed by the diet of a marine bird over multiple time scales. Mar. Ecol. Prog. Ser. 281:207-216.

Miller, P. P.

1985. Life history study of the shortspine thornyhead, *Sebastolobus alascanus,* at Cape Ommaney, south-eastern Alaska. M.S. thesis, 61 p. Univ. Alaska, Fairbanks, AK.

Moser, H. G., and G. W. Boehlert.

1991. Ecology of pelagic larvae and juveniles of the genus *Sebastes.* Environ. Biol. Fish. 30:203-224.

Mosquera, J., M. Gomez-Geistera, and V. Perez-Villar.

1999. Using parasites as biological tags of fish populations: a dynamical model. Bull. Math. Biol. 62:87-99.

Munk, K. M.

2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and considerations of age determination. Alaska Fish. Res. Bull. 8:1-16.

Murphy, J., and J. Ianelli.

2011. Assessment of the thornyhead stock in the Gulf of Alaska. Chapter 15 in: Stock assessment and fishery evaluation report for the 2011 Gulf of Alaska groundfish fishery, p. 1199-1238. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Nelson, J.

1994. Fishes of the World. 3rd ed., 600 p. Wiley, Hoboken, NJ.

Olsen, J. B., S. E. Merkouris, and J. E. Seeb.

2002. An examination of the spatial and temporal genetic variation in walleye pollock (*Theragra chalcogramma*) using allozyme, mitochondrial DNA, and microsatellite data. Fish. Bull. 100:752-764.

Orlov, A. M.

2001. Ocean current patterns and aspects of life history of some northwestern Pacific scorpaenids. *In* Spatial processes and management of marine populations (G. H. Kruse, N. Bez, A. Booth, M. W. Dorn, A. Hills, R. N. Lipcius, D. Pelletier, C. Roy, S. J. Smith, and D. Witherell, eds.), p. 161-184. Alaska Sea Grant Press, Fairbanks AK.

Orr, J. W., and J. E. Blackburn.

2004. The dusky rockfishes (Teleosti: Scorpeaniformes) of the North Pacific Ocean: resurrection of *Sebastes variabilis* (Pallas 1814) and a redescription of *Sebastes ciliatus* (Tilesius 1813). Fish. Bull. 102:328-348.

Owen, R. W.

1980. Eddies of the California Current system: Physical and ecological characteristics. *In* The California Islands: Proceedings of a multidisciplinary symposium (D. M. Power ed.), p. 237-263. Santa Barbara Museum of Natural History, Santa Barbara, CA 93105.

Palof, K.

2008. Population genetic structure of Alaskan Pacific ocean perch (*Sebastes alutus*). M.S. thesis, 72 p. Univ. Alaska, Fairbanks, AK.

Palof, K., J. Heifetz, and A. J. Gharrett.

2010. Geographic structure in Alaska Pacific ocean perch (*Sebastes alutus*) indicates limited lifetime dispersal. Mar. Biol. 158:779-792.

Palumbi, S. R.

1994. Genetic divergence, reproductive isolation, and marine speciation. Ann. Rev. Ecol. Syst. 25:54–57.

Paraketsov, L. A.

1963. On the biology of *Sebastodes alutus* in the Bering Sea. Soviet Fish Invest. N.E. Pac. Part I (Israel Progr. Sci., Trans.), p. 319-327.

Pearcy, W. G., D. L. Stein, M. A. Hixon, E. K. Pikitch, W. H. Barss, and R. M. Starr.

1989. Submersible observations of deep-reef fishes of Heceta Bank. Oregon. Fish. Bull. 87:955-965.

Pearson, K. E., and D. R. Gunderson.

2003. Reproductive biology and ecology of shortspine thornyhead rockfish (*Sebastolobus alascanus)* and longspine thornyhead rockfish (*S. altivelis)* from the northeastern Pacific Ocean. Environ. Biol. Fish. 67:11-136.

Ralston, S., and D. F. Howard.

1995. On the development of year-class strength and cohort variability in two northern California rockfishes. Fish. Bull. 93:710−720.

Reuter, R. F.

1999. Describing dusky rockfish (*Sebastes ciliatus*) habitat in the Gulf of Alaska using historical data. M.S. thesis, 83 p. California State Univ., Hayward, CA.

Reuter, R., and P. Spencer.

2006. BSAI Other Rockfish. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, p. 925-948. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Rocha-Olivares, A., and R. D. Vetter.

1999. Effects of oceanographic circulation on the gene flow, genetic structure, and phylogeography of the rosethorn rockfish (*Sebastes helvomaculatus*). Can. J. Fish. Aquat. Sci. 56:803-811.

Rooper, C. N., and J. L. Boldt.

2005. Distribution of juvenile Pacific ocean perch *Sebastes alutus* in the Aleutian Islands in relation to benthic habitat. Alaska Fish. Res. Bull. 11:102-112.

Rooper, C. N., J. L. Boldt, and M. Zimmermann.

2007. An assessment of Pacific ocean perch *(Sebastes alutus)* habitat use in a deepwater nursery. Est. Coast. Shelf Sci. 75:371–380.

Roques, S., P. Duchesne, and L. Bernatchez.

1999. Potential of microsatellites for individual assignment: The North Atlantic redfish (genus *Sebastes*) species complex as a case study. Mol. Ecol. 8:1703–1717.

Roques, S., J. M. Sevigny, and L. Bernatchez.

2002. Genetic structure of deep-water redfish, *Sebastes mentella*, population across the North Atlantic. Mar. Biol. 140:297–307.

Sasaki, T.

1985. Studies on the sablefish resources in the North Pacific Ocean. Bull. 22:1-108.

Schneider, C. J., T. B. Smith, B. Larson, and C. Moritz.

1999. A test of alternative models of diversification in tropical rainforests: ecological gradients vs. rainforest refugia. Proc. Nat. Acad. Sci. U.S.A. 96:13869-13873.

Scott, B.

2007. Oceanographic features that define the habitat of Pacific ocean perch, *Sebastes alutus*. Fish. Oceanogr. 4:147-157.

Seeb, L. W., and D. R. Gunderson.

1988. Genetic variation and population structure of Pacific ocean perch (*Sebastes alutus*). FAO Fisheries Synopsis No. 79. 38 p.

Shotwell, K., and J. Ianelli.

2012. Assessment of the thornyhead stock in the Gulf of Alaska. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska, p. 617-620. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Sigler, M. F., and J. T. Fujioka.

1988. Evaluation of variability in sablefish, *Anoplopoma fimbria*, abundance indices in the Gulf of Alaska using the bootstrap method. Fish. Bull. 86:445-452.

Soh S., D. R. Gunderson, and D. H. Ito.

2001. The potential role of marine reserves in the management of shortraker rockfish (*Sebastes borealis*) and rougheye rockfish (*Sebastes aleutianus*) in the Gulf of Alaska. Fish. Bull. 99:168-179.

Sonstebo, J. H., R. Borgstrom, and M. Heun.

2007. A comparison of AFLPs and microsatellites to identify the population structure of brown trout (*Salmo trutta* L.) populations from Hardangervidda, Norway. Mol. Ecol. 16:1427-1438.

Spencer, P. D., and J. N. Ianelli.

2010. Assessment of Pacific ocean perch in the Bering Sea/Aleutian Islands. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea and Aleutian Islands Region, p. 1033-1084. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer, P. D., and J. N. Ianelli.

2011. Assessment of Pacific ocean perch in the Bering Sea/Aleutian Islands. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea and Aleutian Islands Region, p. 1059-1062. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer, P. D., and J. N. Ianelli.

2012a. Assessment of northern rockfish the Bering Sea/Aleutian Islands. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea and Aleutian Islands Region, p. 1349-1422. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer, P. D., and R. F. Reuter.

2008. Shortraker rockfish. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea and Aleutian Islands Region, p. 1017-1040. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spencer, P. D., and C. N. Rooper.

2010. Assessment of the shortraker rockfish Stock in the Bering Sea/Aleutian Islands. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea and Aleutian Islands Region, p. 1195-1218. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Spies, I., and P. D. Spencer.

2012. Assessment of the Other rockfish stock complex in the Bering Sea/Aleutian Islands. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea and Aleutian Islands Region, p. 1531-1560. [Available from North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.]

Tsuyuki, H., and S. J. Westrheim.

1970. Analyses of the *Sebastes aleutianus-S. melanostomus* complex, and description of new scorpaenid species, *Sebastes caenaematicus*, in the North-east Pacific Ocean. J. Fish. Res. Board Canada. 27:2233-2254.

Weir, B. S., and C. C. Cockerham.

1984. Estimating *F*-statistics for the analysis of population structure. Evolution 38:1358–1370.

Westrheim, S. J.

1975. Reproduction, maturation, and identification of larvae, of some *Sebastes* (Scorpaenidae) species in the northeast Pacific Ocean. J. Fish. Res. Board Can. 32: 2399-2411.

Williams, E. H., and S. Ralston.

2002. Distribution and co-occurrence of rockfishes (family: *Sebastidae*) over trawlable shelf and slope habitats of California and southern Oregon. Fish. Bull. 100:836-855.

Wing, S. R., L. W. Botsford, S. V. Ralston, and J. L. Largier.

1998. Meroplanktonic distribution and circulation in a coastal retention zone of the northern California upwelling system. Limnol. Oceanogr. 43:1710–1721.

Withler, R. E., T. D. Beacham, A. D. Schulze, L. J. Richards, and K. M. Miller.

2001. Co-existing populations of Pacific ocean perch, *Sebastes alutus*, in Queen Charlotte Sound, British Columbia. Mar. Biol. 139:1–12.

Wourms, J. P.

1991. Reproduction and development of *Sebastes* in the context and evolution of piscine viviparity. Environ. Biol. Fish. 30:111-126.

Yang, M.

1993. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990. NOAA Tech. Memo. NMFS-AFSC-22, 150 p.

Yang, M.

1996. Food habits of the commercially important groundfishes in the Aleutian Islands in summer 1991. NOAA Tech. Memo. NMFS-AFSC-60, 105 p.

Yang, M-S.

2003. Food habits of the important groundfishes in the Aleutian Islands in 1994 and 1999. NMFS-AFSC Proc. Rep. 2003-07, 233 p.

Yang M-S., K. Dodd, R. Hibpshman, and A. Whitehouse.

2006. Food habits of groundfishes in the Gulf of Alaska in 1999 and 2001. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-164, 199 p.

Yang, M., and M. W. Nelson.

2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. NOAA Tech. Memo. NMFS-AFSC-112, 174 p.